ASSESSING JUVENILE SOCKEYE SALMON (*ONCORHYNCHUS NERKA*) ENERGY DENSITIES AND THEIR HABITAT QUALITY IN THE CHIGNIK WATERSHED, ALASKA

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Abstract

The Chignik watershed, on the southern side of the Alaska Peninsula, supports a large salmon fishery vital to the local economy. Recent morphological changes to the watershed generated concern regarding the sockeye salmon (*Oncorhynchus nerka*) stock that rears in Black Lake, at the head of the system. Studies of the Chignik watershed to date have not incorporated energy density data to explain the life history strategies of Chignik sockeye salmon. Re-estimated condition factor parameters improved our understanding of the length-weight relationships to fish health that isometric models described in Chignik sockeye salmon. Subsequent comparisons of age, length, weight, location, and temperature data to energy density indicated that Black Lake fish, which were all age 0 fish, were significantly affected by temperature and had energy densities greater than did fish from other areas of the watershed. Sockeye salmon captured in Chignik Lake, Chignik River, and Chignik Lagoon were only energetically different from one another based on age. Observed seasonal trends suggested juvenile sockeye salmon emigrate from Black Lake before the onset of winter due to forage and temperature limitations. A constant downstream migration occurred in the watershed during the summer, which suggested smoltification and osmoregulation processes in Chignik Lagoon fish.

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Introduction

The Chignik watershed, which is located on the southern side of the Alaska Peninsula, is composed of two lakes, two rivers, a lagoon, and numerous small creeks. The two native stocks of sockeye salmon (*Oncorhynchus nerka*) that reside in the watershed provide the foundation for the Chignik fishery, which drives the local economy.

Black Lake, at the head of the system, is an atypical sockeye salmon nursery lake; it is large (41.1 km^2), shallow (mean depth of 1.9 m, maximum depth 4.2 m; Ruggerone et al. 1993), and semi-turbid. The Black River flows between Black Lake and Chignik Lake, which is large (24.1 km^2) and deep (mean depth of 26 m). Both lakes are considered oligotrophic (Kyle 1992) and each maintains its own genetically distinct sockeye salmon run (Templin et al. 1999). The early run, which returns between June and July (Alaska Department of Fish and Game [ADF&G] escapement goal range between 350,000 to 400,000 sockeye salmon), spawns in Black Lake and its tributaries. The smaller, late run (ADF&G escapement goal range between 200,000 to 250,000 sockeye salmon), the majority of which returns between July and September, utilizes the beaches of Chignik Lake and its tributaries for spawning. Chignik Lake drains into the Chignik Lagoon through the Chignik River. The Chignik Lagoon is tidally influenced, shallow (<15 m), grassy, and possesses of silted and cobbled beaches.

The commercial sockeye salmon fishery in the Chignik management area has been prosecuted since 1922 (Narver 1966). However, it was not until 1967 that the escapement goals, which are still adhered to today, were estimated for Black and Chignik

lakes (Bouwens and Finkle 2003). The carrying capacities of both lakes were separately estimated based on a generalized competitive model; biomass estimates were compared to growth rates and food consumption at age for the four predominant rearing species (sockeye salmon, pond smelt [*Hypomesus olidus*], threespine stickleback [*Gasterosteus aculeatus*], and ninespine stickleback [*Pungitius pungitius*]) in each lake (Narver 1966). Periods of stable growth, high food consumption, and relative increases in sockeye salmon biomass indicated optimal sockeye salmon standing crop, which were compared to the corresponding escapement to the system at that time (Narver 1966). An estimated August Black Lake fry-to-spawner ratio (36.3:1) was used to determine the optimum number of rearing fry in each location based on their respective escapements (Narver 1966). In turn, a five percent fry-to-adult survival was assumed to estimate total run size for that brood year (Narver 1966).

Historic escapements and their magnitudes were compared to establish daily escapement goal ranges for both early and late runs (Pappas et al. 2001). Subsequently, commercial fishery openings have been dependent upon daily escapement goal attainment, test fisheries, and projected run timings (Pappas et al. 2003).

Portions of the Chignik watershed, however, significantly changed in 1970; morphological events altered the flow of the Black River (Ruggerone et al. 1999). A natural sill created at the confluence of the Black and West Fork rivers, which acted as a hydrostatic dam to slow the flow of Black Lake effluent, was lost when the confluence moved approximately five kilometers downstream (Buffington 2001). The loss of this sill increased Black River's gradient, thus flow velocity, causing Black Lake to drain at a faster rate (Buffington 2001).

Concern was expressed by area fishermen and local subsistence users in the 1980s that sockeye salmon rearing habitat might be compromised in Black Lake based on weak sockeye salmon returns that have intermittently occurred over the last 30 years (Pappas et al. 2001). Increased competition (Parr 1972; Ruggerone et al. 1999) and reduced winter dissolved oxygen levels (Ruggerone 1999) have been attributed to the reduction in lake water volume. These factors can lead to a decline in condition, and potentially cause mortality in juvenile fish, if food is not available to maintain the energy levels that meet metabolic costs (Solomon and Brafield 1972; Brett 1979) or if oxygen is not in sufficient supply for respiration (Moyle and Cech 1982; Ruggerone 1999).

Preliminary data from the 2001 and 2002 ADF&G ecological assessment have indicated that Black Lake, Chignik Lake, Chignik River, and Chignik Lagoon each offer different types of forage and physical rearing conditions for juvenile sockeye salmon (Bouwens and Finkle 2003). Assessing the life history strategies of Chignik juvenile sockeye salmon relative to the current environment may indicate changes in sockeye salmon health because of the morphological changes to the watershed. Thus, changes to juvenile sockeye salmon health may indicate shifts in resource availability and usage, which may ultimately affect the carrying capacity of the system.

In-season stock identification of juvenile sockeye salmon is currently not possible, which prevents accurate assessments of each stock's abundance, migratory trends, and habitat use (Bouwens and Finkle 2001). Because each stock cannot be distinguished from the other, it is not possible to identify exactly when Black Lake fish enter Chignik Lake, and subsequent migratory behavior or stock-specific forage preference. This in turn precludes the determination of stock-specific life history

strategies, and potentially increases the error inherent in determining spawner-recruit relationships for each stock. With bioenergetic, length, and weight data, it may be possible to either identify or rule out factors that influence the life history strategies of juvenile sockeye salmon in the watershed.

Energy density data combined with age, length, and weight data may indicate significant trends for Chignik juvenile sockeye salmon in energy storage and utilization, which length and weight data alone may obfuscate. Environmental factors do not directly influence growth; the effects are manifested through energy supply and demand (Brett 1976). For example, the adaptations of a fish to increased temperature can increase the energetic costs associated with increased respiration, consumption, evacuation, and maintenance rates (Elliot and Persson 1978; Arrhenius and Hansson 1994). These expenditures may be "paid" by the fish utilizing its lipid stores, despite forage availability, causing a decrease in mass despite being exposed to conditions that are normally assumed more favorable for growth.

Energy densities, which reflect a summary of protein, fat, water, and ash content in somatic tissue, are useful in fisheries population dynamics modeling (Rudstam et al. 1994; Bowen et al. 1995). Specifically, energy densities may quantify the fat and protein available for growth and maintenance, and subsequently its expenditure, indicating the health and/or rearing strategies of a stock or cohort of fish (Metcalfe and Thorpe 1992; Bowen et al. 1995; Boldt 1997; Tucker and Rasmussen 1999). By knowing the energy requirements of a species of fish, it may be possible to validate patterns of feeding, habitat use, and life history strategies and therefore, determine the rearing limitations of an aquatic system based on resource availability, energetic expenditures, and

consumption demands (Brett et al. 1969; Beauchamp et al. 1989; Davis et al. 1998; Nislow et al. 2000).

Paired with bioenergetic data, length and weight data can be used to model growth (Beauchamp et al. 1989; Rand and Stewart 1997; Nislow et al. 2000). Beauchamp et al. (1989) used mathematical models to suggest that body energy density, relative to weight, increased in adult sockeye salmon until they began their upstream migration to spawn. It may also be possible to determine the onset of metamorphic stages such as smoltification, overwintering, or reproduction, which influence rearing strategies and survival (Metcalfe and Thorpe 1992; Bowen et al. 1995; Boldt 1997; Jonsson et al. 1997). Based on length, weight, and estimated lipid content data, juvenile Atlantic salmon (*Salmo salar*), which began smoltification in the winter, might have maintained their growth, while those juveniles that did not smolt might have experienced controlled anorexia (Metcalfe and Thorpe 1992). Energetic data has been used to indicate when Atlantic salmon and brown trout (*Salmo trutta*) moved into the next age-class (Berg and Bremset 1998). However, in currently available literature, observed changes in energy densities associated with smoltification and overwintering are not reported for Chignik watershed juvenile sockeye salmon. Although bioenergetic parameter estimates do exist for sockeye salmon, parameter values are size- and stock-specific (Cianelli et al. 1998). Additionally, juvenile fish are highly sensitive to temperature (Cianelli et al. 1998). Great variability also exists in the energetic values of a single species of fish in different locations, suggesting cautionary use of cited parameter values (Hansen et al. 1993).

Length and weight observations are popular tools for assessing growth, as they are easy and cost-efficient to collect. These data are valuable because as developing fish

pass through growth stanzas, they may have distinct length-weight relationships during these periods (Bagenal 1978). Separate relationships have been established to quantify absolute, relative, and instantaneous rates of increase in both length and weight (Ricker 1975). Similarly, log transformations of length and weight yield the linear expression:

$$\log W = \log a + B \log L \qquad [1]$$

where W is weight, L is length, a is a species-specific constant, and B is a coefficient representing the curvature of the length-weight relationship with a value usually between two and four (Le Cren 1951; Ricker 1975; Bagenal 1978; Anderson and Gutreuter 1983; Quinn and Deriso 1999). Le Cren (1951) developed the relative condition factor:

$$K_B = W / (a \times L^B) \qquad [2]$$

A special case of the relative condition factor is Fulton's Condition Factor (K), which states

$$K = (100 \times W) / L^3 \qquad [3]$$

where the coefficient of B = three depicts isometric growth (the body proportions and specific gravity do not change with growth; Bagenal 1978). Both models are used to indicate that at a given length the heavier a fish is, the healthier the fish is. However, Le Cren's model allows the condition factor to be fitted to the specific relationship between length and weight as described in equation [1] by determining the slope, B, of the line. The flexibility in Le Cren's model is preferential over Fulton-type models because it allows the model to be tailored to specific conditions and does not assume that fish have isometric, cubic growth.

Despite the allometry of Le Cren's model, there are still significant limitations associated with the estimation of the condition factor. Fixed length-weight relationships

cannot account for periods of changing nutritional status of a fish (Broekhuizen et al. 1994). Broekhuizen et al. (1994) also stated that values of K can appear counterintuitive; it would be unlikely that a short, fat fish and a long, skinny fish would have the same growth rates despite similar values of K, which would misrepresent the life history strategy of the fish. Condition factor data, from either Fulton-type or relative models, do not accurately reflect the proportions of energy (in the form of protein and fat) and water in tissue, which contribute to an individual's weight. Therefore, the energy available for growth or maintenance cannot be accurately quantified as health with length-based condition factor data alone.

Energy density, water content, and total weight of an individual from a cohort of fish may provide a truer indication of health relative to length and weight. Correlations have been found between energy density, condition factor, length, and/or weight data in herring (*Clupea* spp.; Perkins and Dahlberg 1971; Boldt 1997), walleye pollock (*Theragra chalcogramma*; Boldt 1997), brook trout (*Salvelinus fontinalis*; Hutchings 1993), and yellow perch (*Perca fluviatilis*; Le Cren 1951; Craig 1977). This would suggest that incorporating energy density into length and weight studies of the Chignik watershed fish may prove valuable. Bioenergetic studies of juvenile sockeye salmon at age may reveal energy density levels associated with metamorphic stages, which may facilitate a better understanding of the Chignik sockeye salmon life histories.

This study seeks to establish a baseline for assessing bioenergetic factors, which influence the growth and health, as defined by condition and energy density, of juvenile sockeye salmon in the Chignik watershed. The goal of this study is to elucidate trends in growth and habitat use of juvenile sockeye salmon in the watershed with energy density

data, which length and weight data alone cannot clearly or accurately address. Comparing age, size, temperature, and energy density may indicate preferred nursery areas, the occurrence of smoltification of juvenile sockeye salmon, and define juvenile migratory trends or early life history strategies. Energy density data paired with condition factor data may also provide a more reliable assessment of in-season fish health, which could be useful in determining if the carrying capacities of Black and Chignik lakes efficiently maintain and support their current recruitment levels.

The first objective of the study is to assess the correlation between condition factor data and energy densities of juvenile sockeye salmon in the Chignik watershed. The following hypotheses will be tested

1. H_O: Fulton's Condition Factor can be used to provide an accurate description of the relationship between length and weight of juvenile sockeye salmon in the Chignik watershed.

H_A: The relative condition factor is significantly better.

2. H_O: Relative condition factor does not correlate with the energy densities of juvenile sockeye salmon from the Chignik watershed.

H_A: Relative condition factor does correlate with energy densities.

The second objective of this study is to examine the relationship between growth, as defined by changes in length and weight, and energy densities of juvenile sockeye salmon. The hypothesis to be tested is

3. H_O: Length and weight do not change proportionally to energy densities in juvenile sockeye salmon.

H_A: Length and weight do change proportionally to energy densities.

The third objective is to assess growth differences of juvenile sockeye salmon among Black Lake, Chignik Lake, Chignik River, and Chignik Lagoon. Due to the littoral nature of Black Lake, temperatures are consistently warmer in Black Lake than in Chignik Lake; this may also play a significant role in the rearing strategies of juvenile sockeye salmon in the watershed, especially because Black Lake possesses only age 0 sockeye salmon (Jensen and Johnsen 1999; Bouwens and Finkle 2001; Finlay et al. 2001). The hypotheses to be tested are

4. H_O: Energy densities of juvenile sockeye salmon of similar length are not significantly different among the four rearing areas in the Chignik watershed.

H_A: Energy densities of juvenile sockeye salmon of similar length are significantly different.

5. H_O: Age 1 sockeye salmon in the Chignik watershed do not exhibit greater energy densities than age 0 sockeye salmon.

H_A: Age 1 sockeye salmon in the Chignik watershed do exhibit greater energy densities.

6. H_O: Energy densities of juvenile sockeye salmon of similar length, which are captured in each of the four rearing areas of the Chignik watershed, are not correlated with the temperatures in each of the four respective rearing areas in the Chignik watershed.

H_A: Energy densities of juvenile sockeye salmon of similar length are correlated with the temperatures.

Materials and Methods

Field Procedures

Juvenile sockeye salmon were collected with a beach seine from the Chignik watershed (Figure 1) on the Alaska Peninsula from June 4 to August 5, 2002. Sampling locations were divided into Black Lake (Figure 2), Chignik Lake (Figure 3), Chignik River (Figure 4), and Chignik Lagoon (Figure 5). Eighteen sites determined by the ongoing ADF&G ecological assessment (Bouwens and Finkle 2003) were sampled once every two weeks throughout the watershed: four Black Lake sites, seven Chignik Lake sites, three Chignik River sites, and four Chignik Lagoon sites (Table 1; Figures 2 to 5). Temperature data were collected throughout the watershed during the course of the study.

Ongoing studies of the Chignik watershed conducted by the ADF&G utilized pelagic trawls (Bouwens and Finkle 2003) to assess juvenile sockeye salmon rearing offshore in Chignik Lake. T-test comparisons of mean log length at age between trawl and beach seine captured sockeye salmon indicated that near-shore and offshore fish were not significantly different; this implies that beach seine captured juvenile sockeye salmon are a fair representation of the sockeye salmon throughout Chignik Lake. Trawls performed by ADF&G and the Fisheries Research Institute (FRI) in Black Lake yielded the same comparison between near-shore and offshore rearing fish.

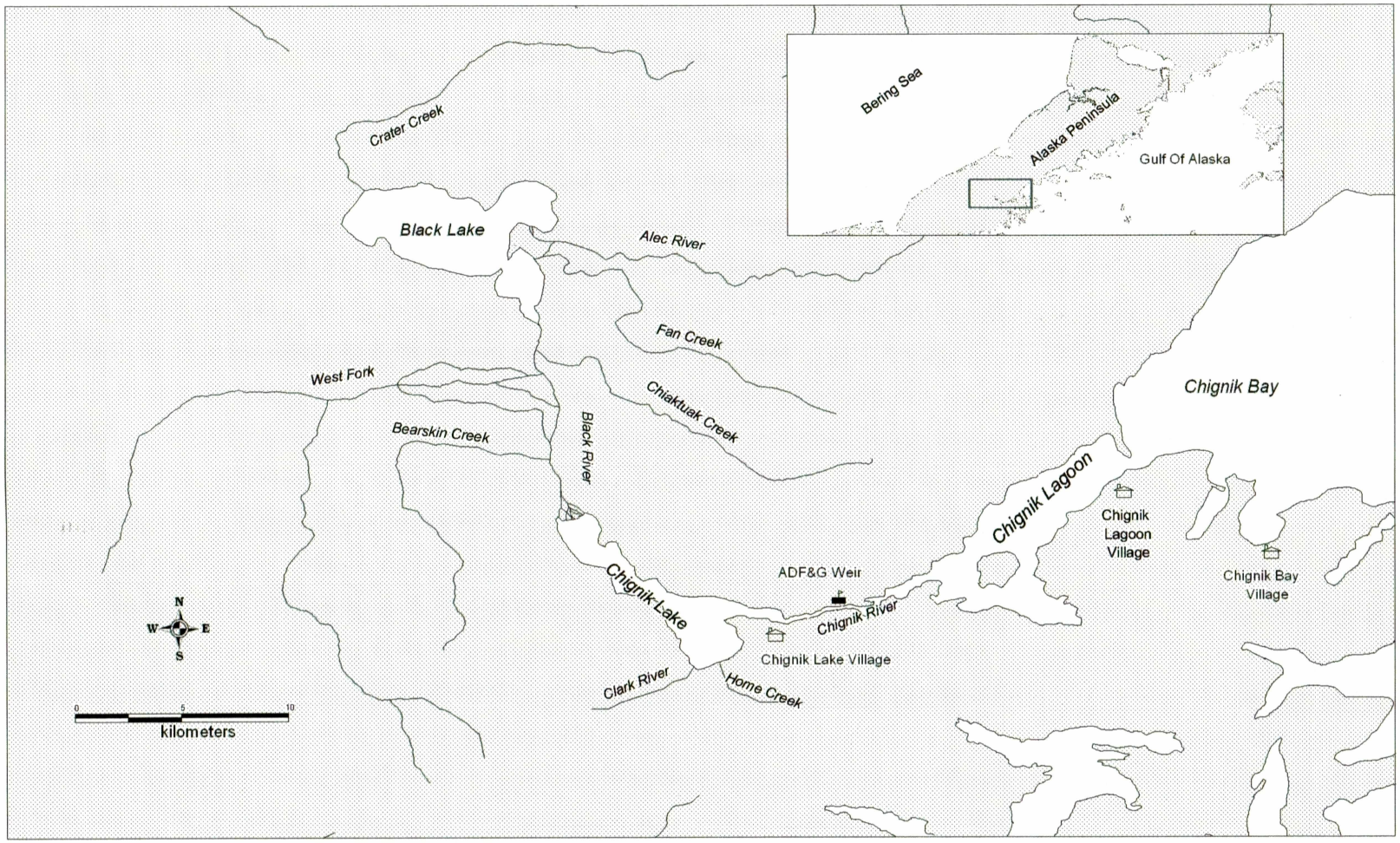

Figure 1. Map of the Chignik watershed with an inset of the Alaska Peninsula.

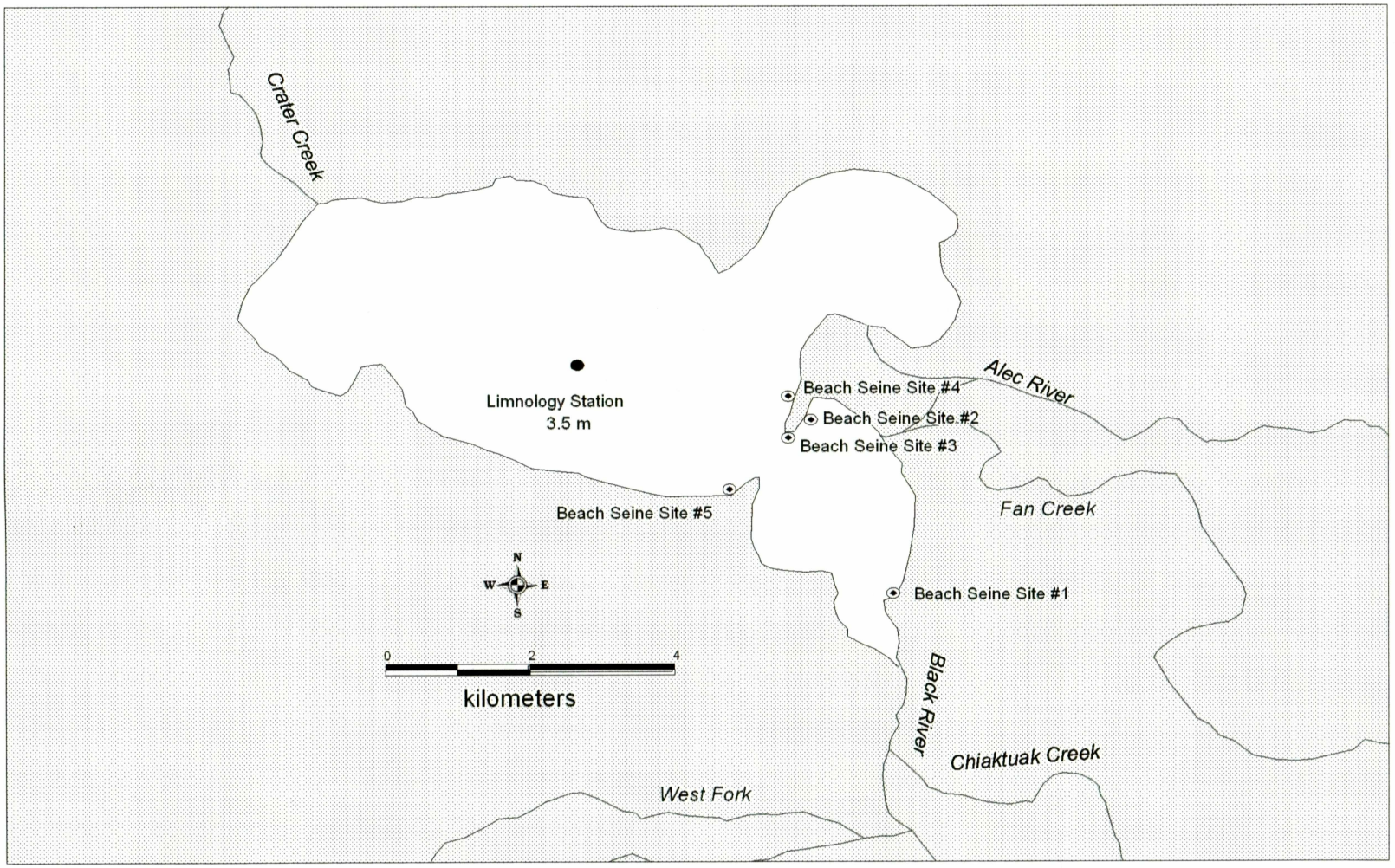

Figure 2. Map of Black Lake and its sampling sites. The limnology station's total depth is shown.

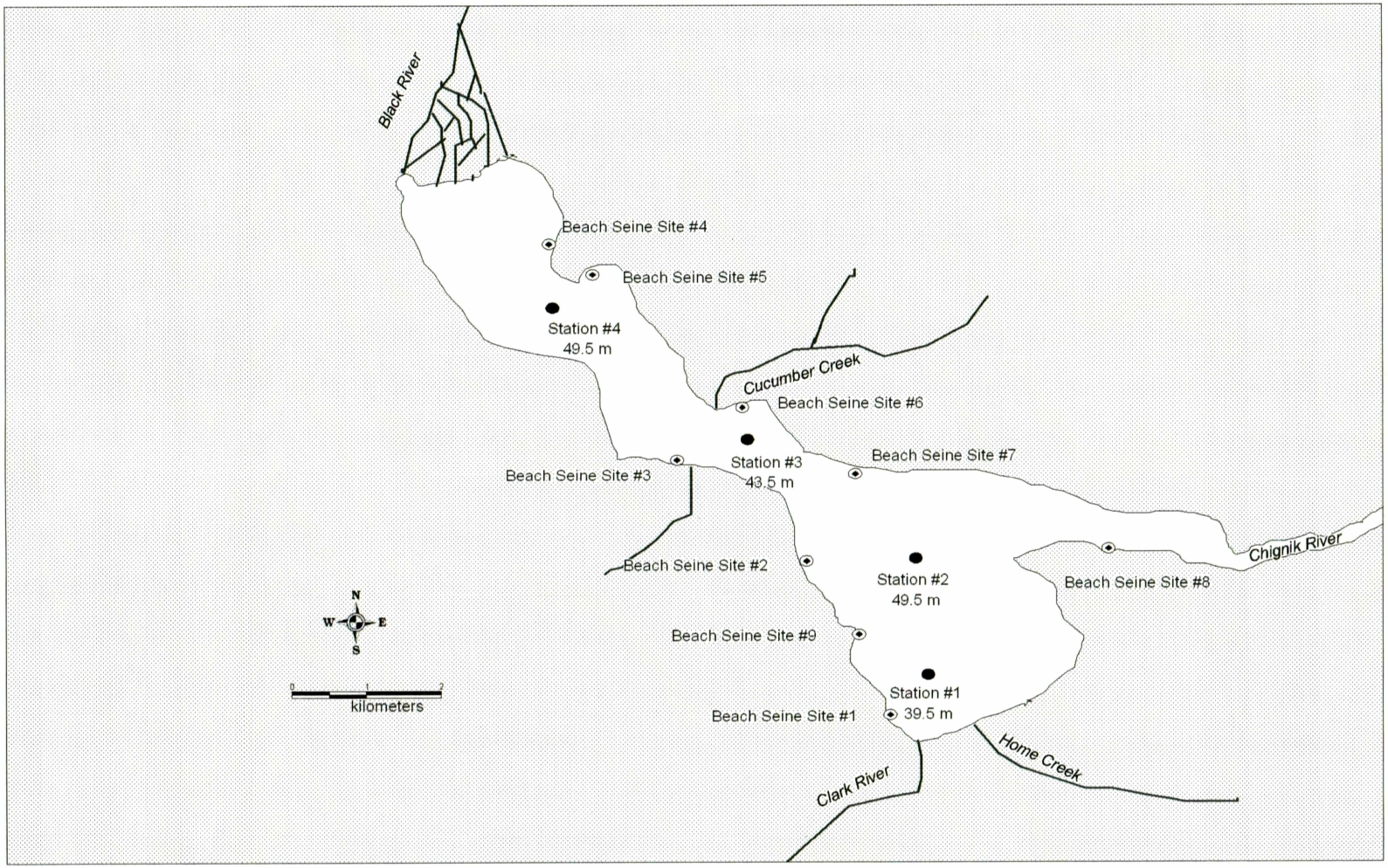

Figure 3. Map of Chignik Lake and its sampling sites.

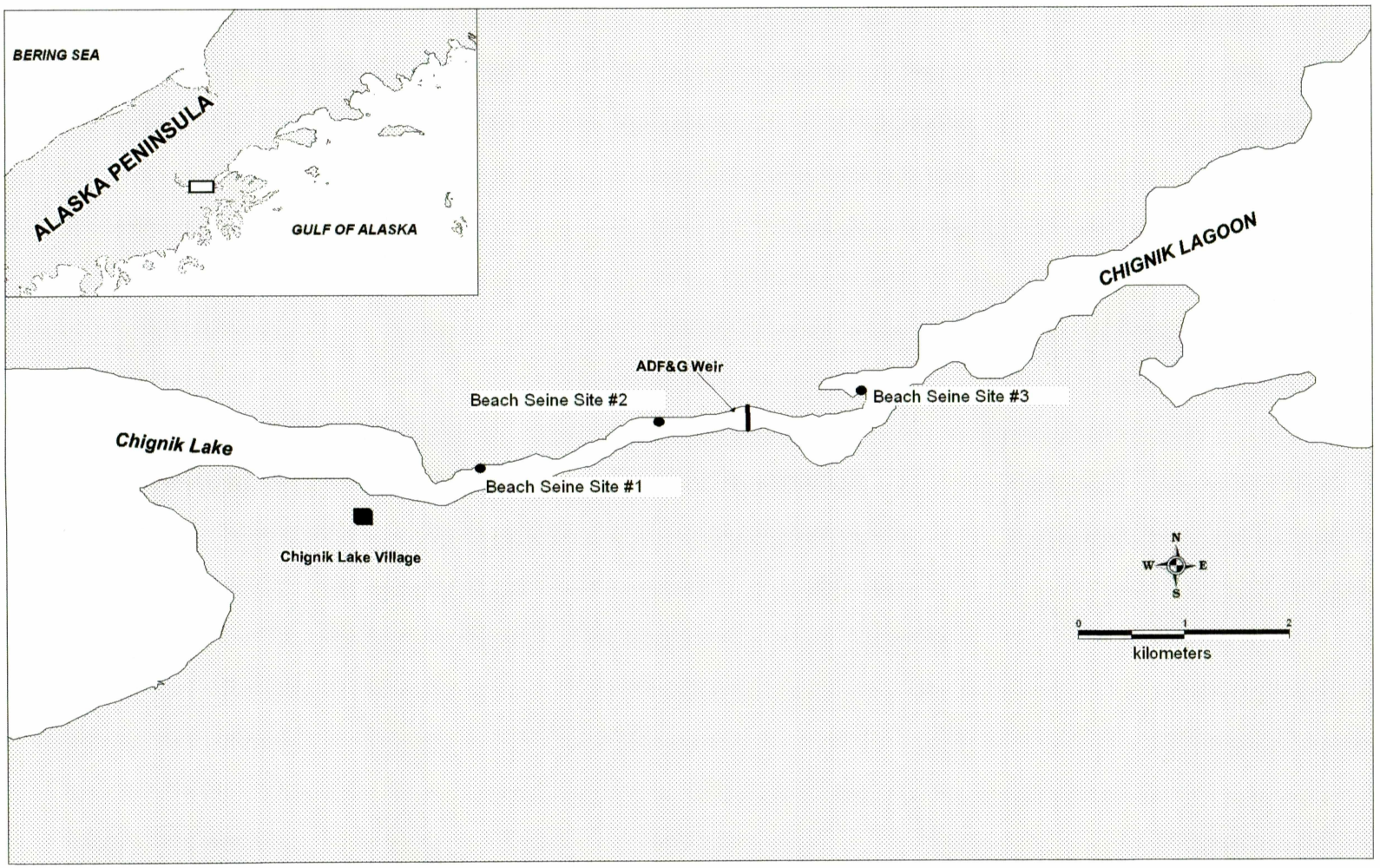

Figure 4. Map of Chignik River and its sampling sites.

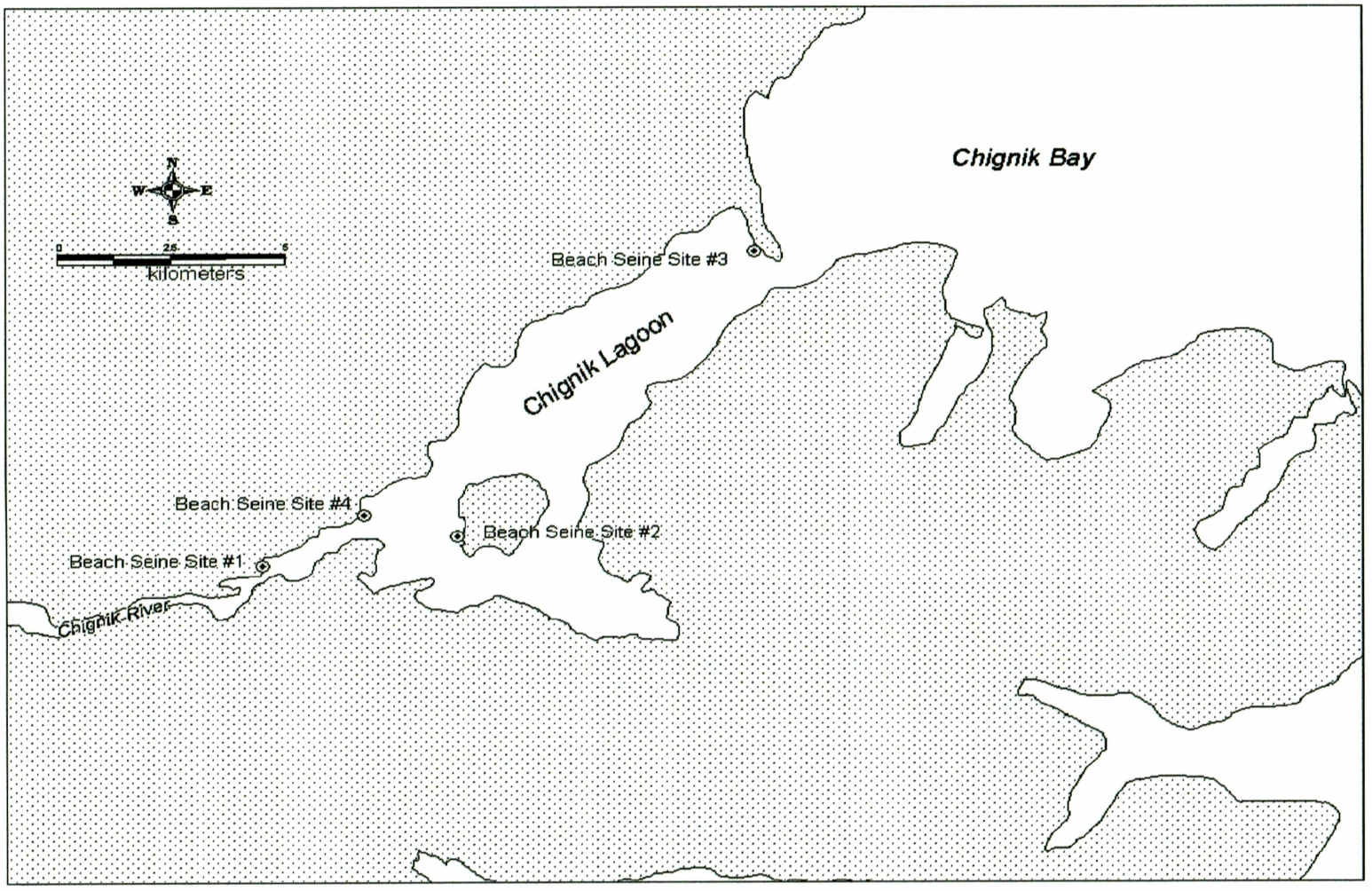

Figure 5. Map of Chignik Lagoon and its sampling sites.

Table 1. Beach seine sampling site locations in the Chignik Watershed, 2002.

Location	Site	Latitude	Longitude
Black Lake	1	56°27.207 N	158°56.375 W
	2	56°26.852 N	158°57.618 W
	4	NA	NA
	5	NA	NA
Chignik Lake	1	56°15.201 N	158°50.619 W
	2	56°13.777 N	158°19.283 W
	3	56°16.080 N	158°51.856 W
	5	56°18.027 N	158°53.525 W
	6	56°17.759 N	158°53.113 W
	7	NA	NA
	8	56°15.381 N	158°46.810 W
Chignik River	1	56°15.701 N	158°44.895 W
	2	56°15.701 N	158°42.677 W
	3	56°15.889 N	158°41.220 W
Lagoon	1	56°16.275 N	158°40.459 W
	2	56°17.187 N	158°36.227 W
	3	56°20.396 N	158°29.506 W
	4	56°16.730 N	158°38.649 W

Temperature Data

Surface temperature data were collected with a mercury thermometer and recorded to the nearest 0.5 °C at each site at the time of the sampling event. Onset Hobo® thermographs were deployed from the Black Lake limnology station (Figure 2) on June 7, 2002 at a depth of 1 m. Only one thermograph was deployed in Black Lake because its mean depth is 1.5 m (Bouwens and Finkle 2003), which is too shallow to set another temperature logger. The Black Lake thermograph recorded temperatures every two hours and was retrieved on August 16, 2002. Thermographs were deployed at the Station 2 Chignik Lake limnology station to depths of 1 m and 29 m (Figure 3) on May 14, 2002 and were retrieved on August 18, 2002. Chignik Lake thermograph temperatures were recorded hourly. Temperature-depth profiles were collected roughly once every four weeks (Table 2) from both Chignik and Black Lakes. Five preexisting ADF&G limnological stations (Bouwens and Finkle 2003) were used as profile locations; one station was on Black Lake and four were on Chignik Lake. Measurements were taken with a WTW Oxi 197 meter at 0.5 m intervals for the first five meters of the water column, after which readings were taken at 1.0 m intervals until a maximum depth of 50 m or the lake bottom was reached. The meter was calibrated before each day's use by comparison to a mercury thermometer. Data from the Chignik Lake stations were averaged each month to provide a mean monthly Chignik Lake temperature profile because they were similar at depth.

Table 2. Dates of temperature profiling events in Black and Chignik lakes, 2002.

Location	Date
Black Lake	June 22, 2002
	July 20, 2002
Chignik Lake	June 19, 2002
	July 24, 2002
	August 14, 2002

Beach Seine Sampling

A beach seine, which was 1 m deep, 10 m long, with 3 mm mesh, was used to collect fish from each site on a biweekly basis from June 4 to August 5, 2002. The sampling sequence commenced in Chignik Lagoon and proceeded upstream to Black Lake to minimize capturing the same fish during downstream migration. The net was set once at each site unless it deployed poorly. Two people made the sets with one person acting as the anchor on shore and the other person wading off shore to make the hook. When inclement weather conditions or steep, abrupt bottom profiles were encountered, a motorized skiff was used to make the hook. All captured species of fish were identified, enumerated, and their abundances recorded. A maximum of five randomly chosen juvenile sockeye salmon was collected to represent each size group. Three size groups, a small size group (< 46 mm), a medium size group (46 to 65 mm), and a large size group (>65 mm), were determined. Size groups were established to allow for replication in data analyses with length and to accommodate variable comparisons when a size group may not be present in a particular location in the watershed. Partitioning the sampled fish into size groups may also capture and elucidate trends in energy storage, growth stanzas, or over-wintering of age 0 or age 1 fish (small to medium), smoltification of age 0 or age 1 fish (all size groups), or any other metabolically taxing events as its energy demands change (Bagenal 1978). Fork length measurements were verified prior to storing the fish in water in separate Ziploc® bags for transport to the field lab.

Laboratory Procedures

Ages, lengths, wet weights, dry weights, condition factor values, and energy densities were determined for juvenile sockeye salmon. A total sample size was calculated based on power analyses as described by Zar (1999) for a one-way analysis of variance (α=0.05, t=1.96, variance estimated at 105,785.88) and correlation comparison. The greatest sample size required of all the analytical methods, which would offer less than a twenty percent chance of committing a Type II error size, was determined to be 100 juvenile sockeye salmon. The variance was estimated from preliminary analyses, as the available literature did not provide a related value. A total of 118 juvenile sockeye salmon were analyzed for their caloric content to allow for replication among size groups.

Age, Length, and Wet Weight

Fork length (± 1.0 mm) and wet weight (± 0.1 g) measurements were recorded for all captured juvenile sockeye salmon. Fish were blotted on a paper towel to remove excess moisture prior to weight measurements. Multiple scales were collected from the preferred area (INPFC 1963) of each fish and placed on a labeled glass slide. Scales were aged with an Eyecom 3000 microfiche reader under 60 times magnification following the methods of Koo (1962). All fish were individually stored and frozen at -10 to -20 °C in labeled Whirl-pak® bags until they could be freeze-dried.

Dry Weight

Each juvenile sockeye salmon was freeze-dried in its respective, opened, Whirl-pak® bag at -40°C until there was no noticeable weight change (approximately 4 days). Each fish was removed from its bag and weighed on a tared piece of paper to the nearest 0.001 g. A dried fish was replaced in its Whirl-pak® bag and stored frozen in a Ziploc® bag with dessicant until energy densities could be measured. The difference between the wet weight and the dry weight was documented as water content of the sample. Fish were dried no more than five days prior to caloric content analysis to minimize moisture reabsorption.

Energy Density

Energy densities for each fish were determined using a Parr 1425 Semimicro bomb calorimeter. Approximately 0.05 g to 0.15 g of the dried sample was formed into a pellet using a pellet press after homogenizing the fish. Fish less than or equal to 0.15 g were pressed whole. Pellets were weighed to the nearest 0.001 g immediately after pressing and stored in a dessicator until they could be analyzed in the calorimeter. The methods used for assessing energy densities were stated in the Parr Operating Instructions (Parr CO. 1994). The calorimeter was calibrated with a manufacturer-supplied standard of benzoic acid before its initial use and periodically thereafter. The fuse wire used was a nickel alloy (No. 45C10), which has 1,400 cal/g or 2.3 cal/cm. Fuse wire that was not burned during the combustion process was measured, documented, and accounted for in

the final caloric value of the sample. Sulfuric and nitric acids formed during the bombing process were considered negligible and not corrected for based on the findings of Boldt (UAF, personal communication, 2002). The formula (Parr CO. 1994; Boldt 1997) for determining the energy density of a sample was

Energy density $=H_C=(W\Delta T - e_1 - e_2 - e_3)/m$, where [4]

H_C = Heat of combustion in calories/g,

W= Energy equivalent of the bomb (the amount of energy required to raise the temperature of the calorimeter 1°C),

ΔT = Temperature change in °C,

e_1 = Heat from burning N_2 in calories/g, assume = 0,

e_2 = Heat from burning S in calories/g, assume = 0,

e_3 = Heat from burning wire (amount used) in calories/g, and

m= sample mass (g).

Observed seasonal trends in the change of energy density of Chignik watershed juvenile sockeye salmon over the 2002 sampling period were compared via seasonal averages. Mean energy densities (calories/g) for each sampling date were calculated for each age class by location to highlight general trends and fluctuations in energy density. Mean surface temperatures from the sample dates were also included in the comparison.

Observed Seasonal Trends in Length and Weight

Observed seasonal trends in the changes of length and dry weight during the 2002 sampling period were compared following the same methods as previously described for

energy density. Mean lengths (mm) and dry weights (g) were calculated for each age group by location and compared to the sample date and mean surface temperature.

Condition Factor

Condition factor values for each fish were calculated using both Fulton's and the relative condition factor indices. Fulton's model was chosen for comparison because it is currently used for fisheries research by the ADF&G. Fulton's Condition Factor, expressed in equation [3], is a special case of the relative condition factor with a coefficient value of $B = 3$. The species-specific constant a was estimated with the coefficient B set at a value of three to enable comparison to the relative condition factor model. Equation [2] was used to determine the relative condition factor. The relative condition factor was chosen over other models because it does not assume that fish have isometric growth.

Data Analysis

The "R" statistical package was employed to perform regression diagnostics and run statistical models (Venebals and Ripley 1999). A Wilcoxon Mann-Whitney test was run to compare the distributions of energy density data among the sample sites within their respective locations to allow for data pooling within each location. The Wilcoxon Mann-Whitney test was chosen because, although it can accommodate normally distributed data, it does not assume that the data are normally distributed. The test

revealed that the distributions of energy density data from each site within a given location were not significantly different and that the data could be pooled.

Regression diagnostics were employed to assess non-normality and outlying data points. These diagnostics included box plots, stem and leaf diagrams, quantile plots, and Cook's distance plots. Scatter plots fitted with loess lines were used as indicators of non-linearity. Loess lines were incorporated to provide a nonparametric view of the trends between the independent and dependent variables. Residual-versus-order plots, residual-versus-fitted values, residual box plots, and Cook's distance were compared to determine equal variance, normality, and independence in the data after fitting the regressions.

Length and weight data were log transformed to account for the multiplicative error structure of the data (Zar 1999). Residual plots were used to address the statistical fit of energy density, length, and dry weight to Fulton's condition factor. Condition factor parameters were re-estimated by minimizing the residual sum of squares between observed and predicted values of weight for isometric and allometric models as described by Quinn and Deriso (1999). Confidence intervals for the relative condition factor model were generated for parameter estimates at the 95% level using a nonparametric bootstrap. Correlation analysis was employed to compare log length, log dry weight, and energy density.

Analysis of Covariance (ANCOVA) was used to assess the effects, separately and as interaction terms, of the factors of log length and location upon energy density. The effects of mean surface temperature in each location upon energy density were also compared separately and for interaction via ANCOVA. Location factor levels for both ANCOVA models included Black Lake, Chignik Lake, Chignik River, and Chignik

Lagoon. A full model was initially run and regressed backwards to identify significant factors, and the order in which the significant factors should be placed in the reduced model. Interaction terms were included initially to test for homogeneity of slopes and were removed if no significant differences were found. If interaction occurred, factors were compared to the continuous dependent variables in a simpler regression approach (Glantz and Slinker 2001). Tukey's Honest Significant Differences (Tukey HSD) test was employed to indicate which factor levels were different given a significant difference for that factor. The Tukey HSD was chosen for post-hoc comparisons because it can accommodate moderate differences in sample size and, although conservative, is more robust than a Sheffe's test (Glantz and Slinker 2001). An Analysis of Variance (ANOVA) was used to determine if age 1 sockeye salmon had greater energy densities than age 0 sockeye salmon.

Results

Hypothesis 1

H_O: Fulton's Condition Factor can be used to provide an accurate description of the relationship between length and weight of juvenile sockeye salmon in the Chignik watershed.

Confidence intervals for the relative condition factor *B* failed to contain the isometric value of 3, indicating that the Fulton's Condition Factor is inferior to the relative

condition factor model (Table 3). An F-test comparing the model fits from Fulton's Condition Factor and the relative condition factor models also indicated that B was significantly different than a value of three (F =4.95, P=0.028). Fulton's condition factor, K, was not significantly correlated with energy density (r = 0.096, P>0.05; Table 4). Residual plots of log length, log dry weight, and energy density against Fulton's Condition Factor, K, (Figure 6) also illustrate the variability of the isometric model when describing the length-weight and energy density relationships of Chignik juvenile sockeye salmon.

Hypothesis 2

H_O: Relative condition factor does not correlate with energy densities of juvenile sockeye salmon from the Chignik watershed.

Parameter estimates for the relative condition factor are $a = 6.50 \times 10^{-6}$ and B = 3.12, and provide an excellent fit to the length-weight data (Figure 7) despite having the same variability in log length and energy density as the isometric model (Figures 6 and 8). The correlation coefficient of 0.097 between K_B and energy density (Table 3) was not statistically significant, showing that the relative condition factor model does not provide more meaningful information about energy density than Fulton's Condition Factor.

Table 3. Comparisons of observed and predicted parameter estimates used to calculate log weight. Parameter estimates are based on residual sum of squares regression and correlation coefficients. Confidence intervals (CI) were generated for parameter estimates with the bootstrap percentile method.

Parameter	Original estimate		Predicted estimate	
a	1.04E-05		6.50E-06	
B	3.00		3.12	
RSS	2.474		2.373	
	Lower	Upper	Lower	Upper
Percentile CI				
a	1.01E-05	1.07E-05	4.29E-06	9.93E-06
B	NA	NA	3.01	3.23
Correlation coefficient of K to energy density	0.096		0.097	
Correlation coefficient *P*	0.299		0.152	

Table 4. Correlation coefficients and p-values of log length and log dry weight compared to K for Chignik watershed sockeye salmon, 2002. All size groups were pooled for analyses.

Independent variable	Correlation coefficient *r*	Correlation coefficient *P*
Log (Length)	0.176	0.536
Log (Dry Weight)	0.243	0.008

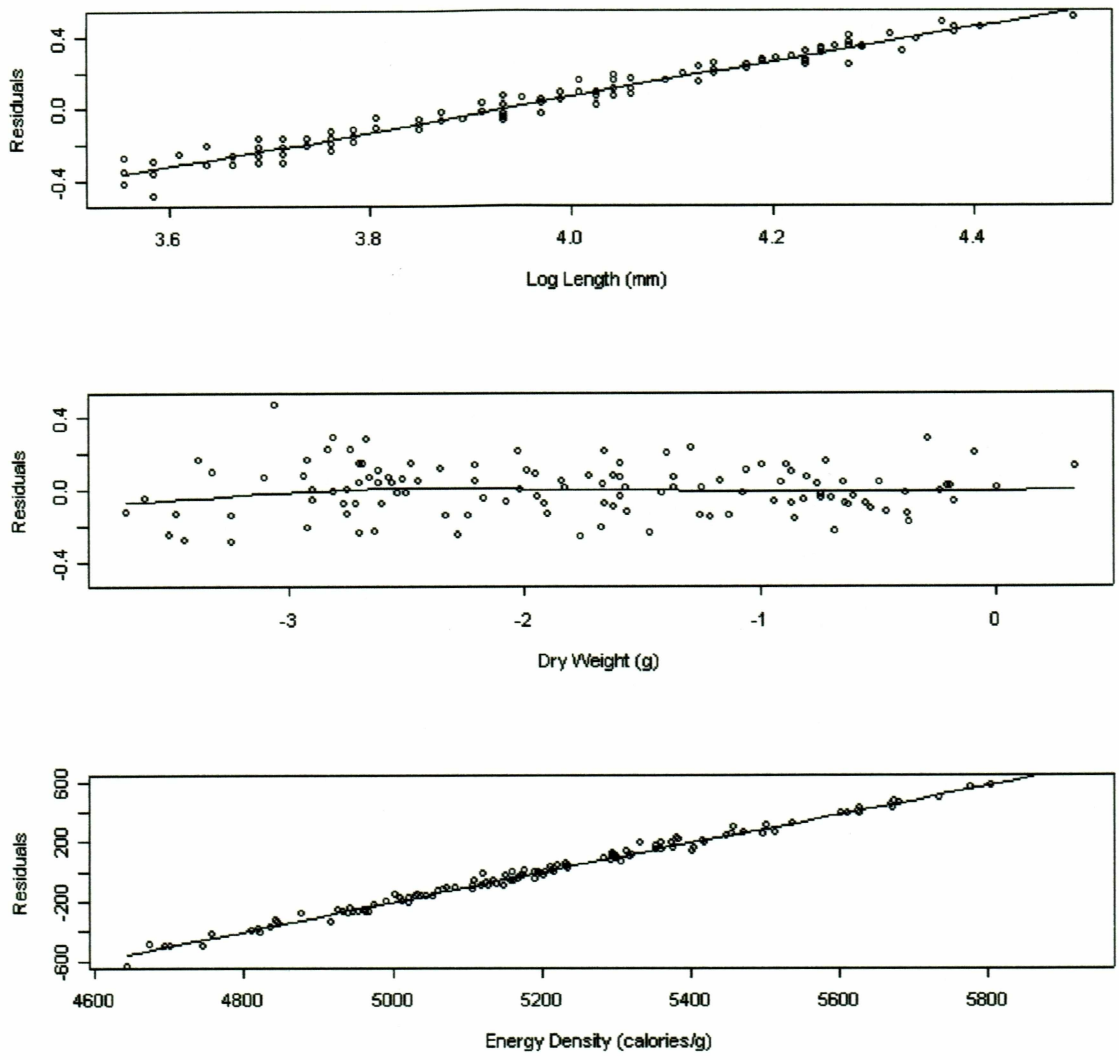

Figure 6. Plots of residuals against log length, log dry weight, and energy density for the linear fit to Fulton's Condition Factor model for Chignik watershed juvenile sockeye salmon, 2002. All plots are fitted with loess lines.

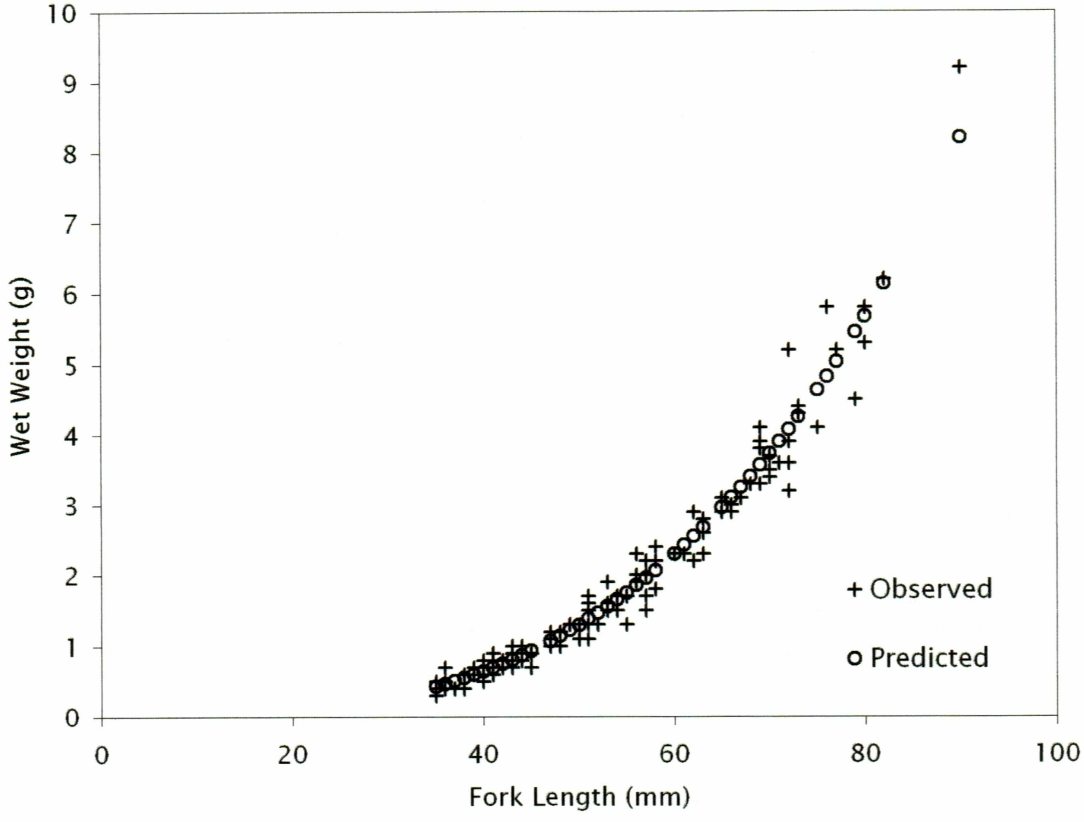

Figure 7. Observed and predicted values of weight plotted against length of Chignik watershed sockeye salmon, 2002. Re-estimated parameter values of *a* and *B* are based on the log weight-log length relationship.

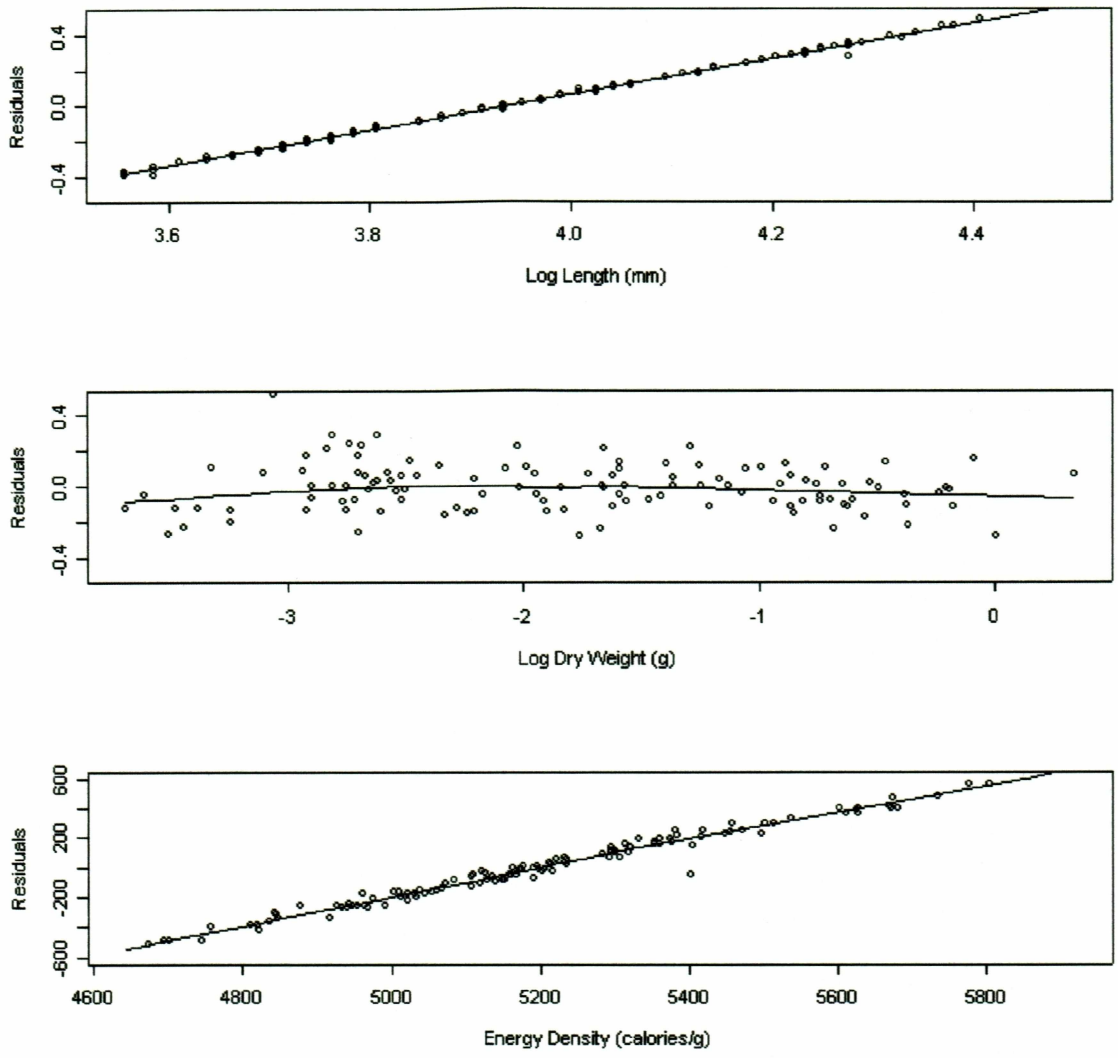

Figure 8. Plots of residuals against log length, log dry weight, and energy density for the linear fit to the relative condition factor model for Chignik watershed juvenile sockeye salmon, 2002. All plots are fitted with loess lines.

Hypothesis 3

H_O: Length and weight do not change proportionally to energy density in juvenile sockeye salmon.

The correlations between log length and energy density and between log dry weight and energy density were significant ($P<0.001$) and negative (Table 5, Figure9). Comparisons of the energy densities of each size group using ANOVA and Tukey's HSD revealed significant differences (ANOVA, $P<0.001$, df=2, 116; Figure 10) between the small and medium size groups and between the small and large size groups. The large and medium size groups did not have significantly different energy densities (Figure 10).

Hypothesis 4

H_O: Energy densities of juvenile sockeye salmon of similar length are not significantly different among the four rearing areas in the Chignik watershed.

There were no major differences in energy densities among size groups for juvenile sockeye salmon collected from Black Lake (Figure 11). However, of the fish captured in Chignik Lake, Chignik River, and Chignik Lagoon, small fish had greater energy densities than medium and large fish (Figure 11). Analysis of covariance (ANCOVA) for juvenile sockeye salmon in the small group indicated that location had a significant effect upon energy density ($P<0.05$; Table 6) and that the slope with log

Table 5. Correlations of log length and log dry weight to energy density for Chignik watershed sockeye salmon,2002. Correlation coefficients and *p* -values are shown.

Independent Variable	Correlation coefficent to energy density	*P*
Length	-0.478	3.83E-08
Dry Weight	-0.480	3.33E-08

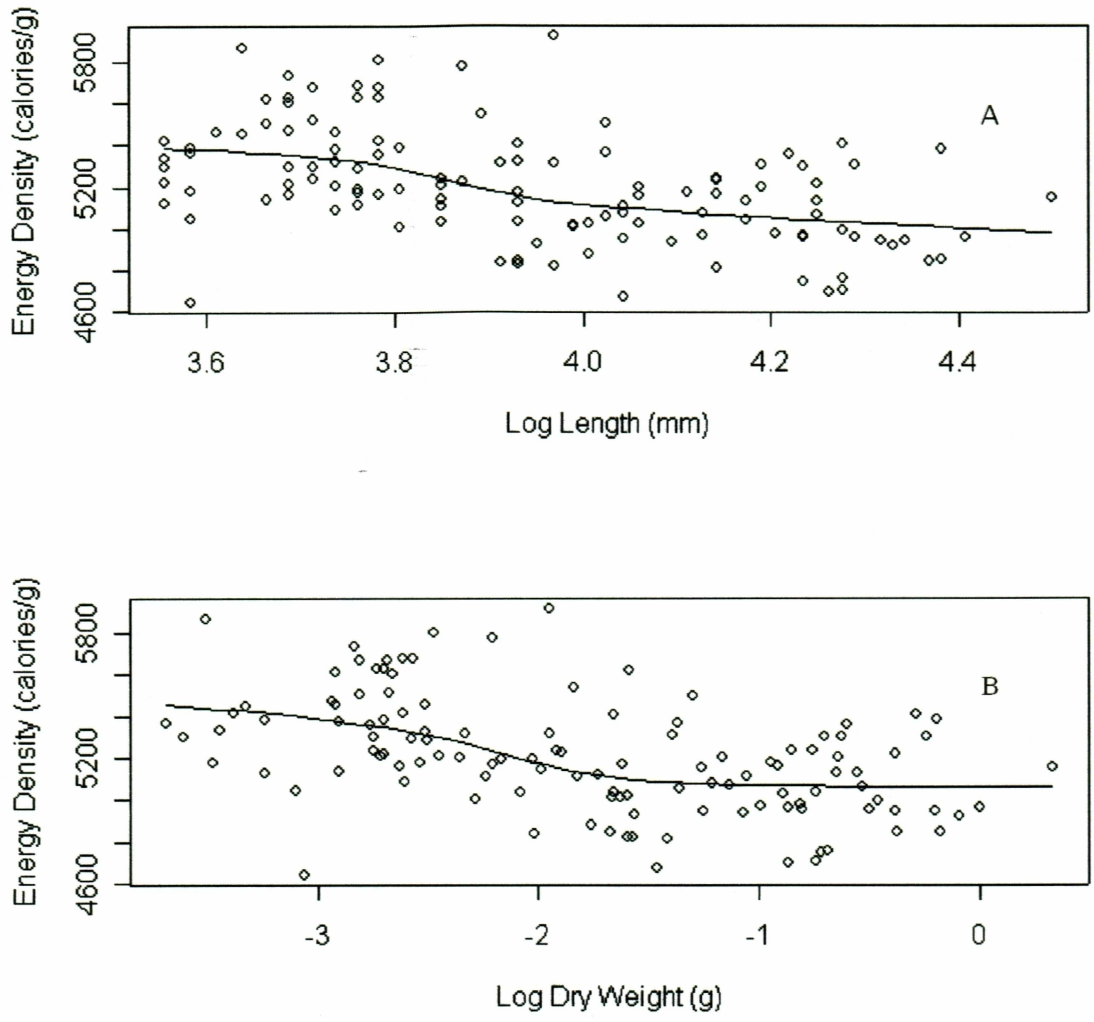

Figure 9. Scatter plots of energy density against log length (A) and log dry weight (B) for juvenile sockeye salmon collected from the Chignik watershed in 2002. Plots have been fitted with loess lines.

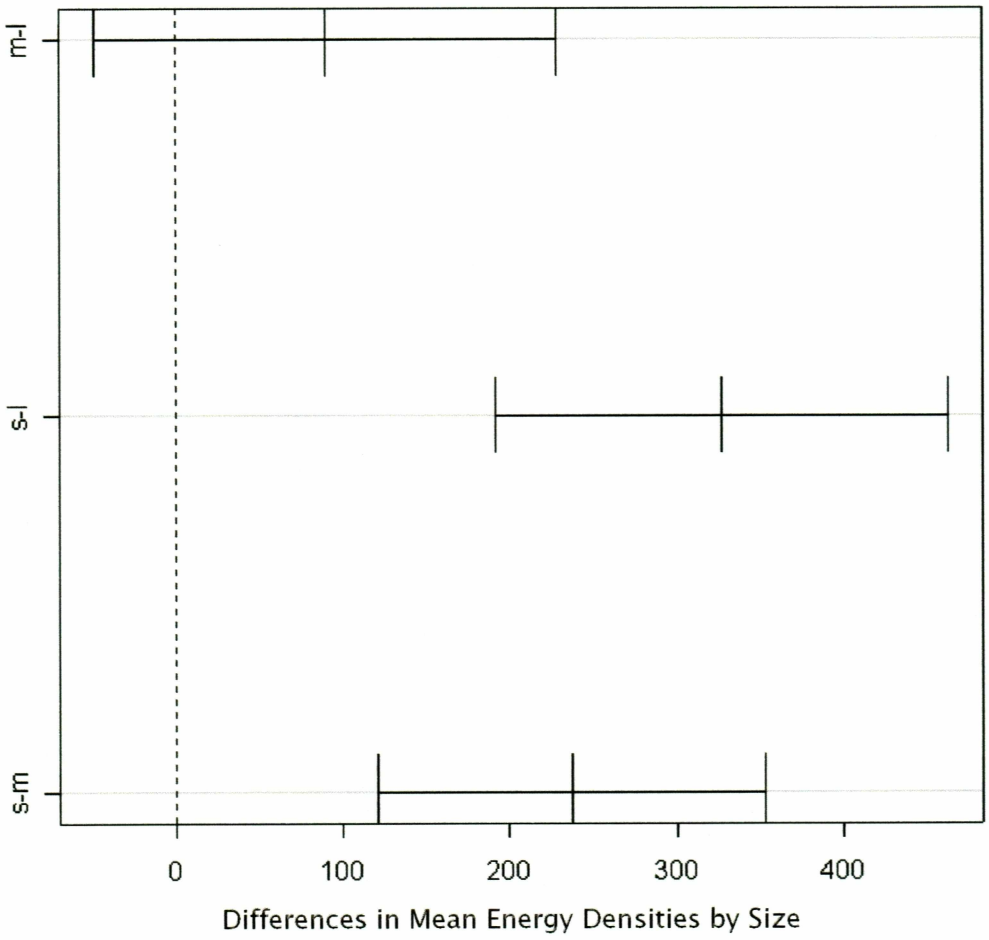

Figure 10. Tukey HSD comparisons of energy densities for each size group of Chignik watershed juvenile sockeye salmon, 2002. Confidence intervals are shown at the 95% level.

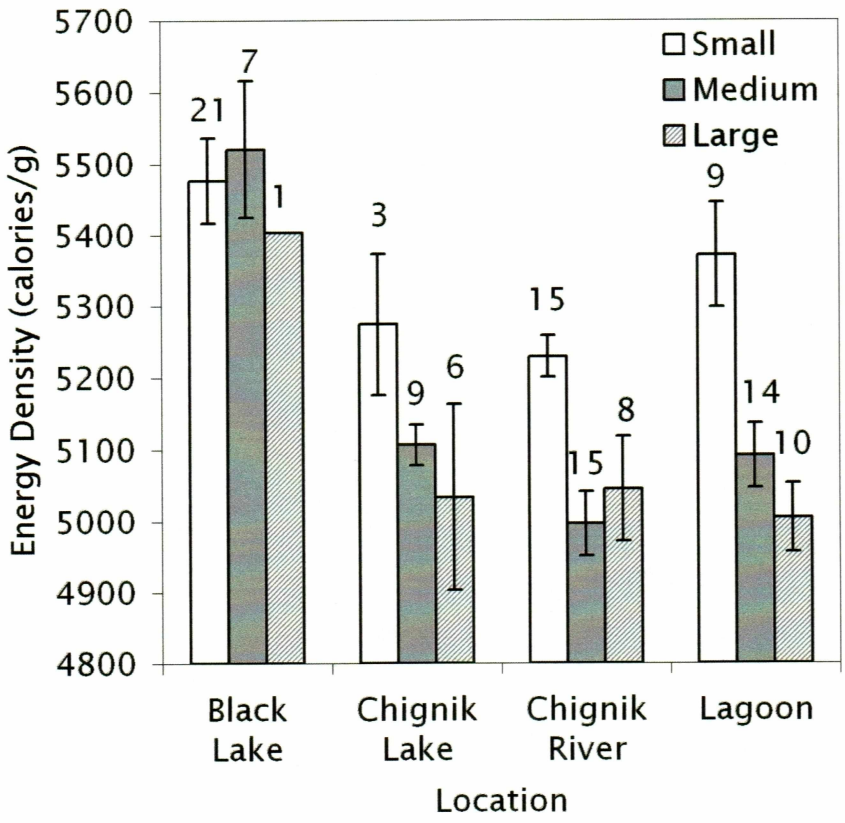

Figure 11. Mean energy density by size group and area for juvenile sockeye salmon collected from the Chignik watershed, 2002. Standard error bars and sample size are also displayed.

Table 6. Analysis of covariance statistics for energy density compared to location and log length. All models are for juvenile sockeye salmon captured in the Chignik watershed, 2002.

Model		F	df	*P*
Small fish				
	Location	6.51	3	0.001
	Log length	3.26	1	0.078
	Location*Log length	7.98	3	0.000
Medium fish				
	Location	12.72	3	<0.001
	Log length	3.77	1	0.060
	Location*Log length	0.78	3	0.513
Large fish				
	Location	1.05	3	0.393
	Log length	0.35	1	0.564
	Location*Log length	1.22	2	0.313

length differs among locations ($P<0.001$; Table 6). Log length alone, within the small size group, did not significantly affect energy density ($P>0.05$; Table 6). Energy densities of juvenile sockeye salmon in the medium size group were significantly affected by their location (ANCOVA, $P<0.001$; Table 6), However. log length within the medium size group did not affect energy density, nor was there any interaction effect between location and log length upon energy density (ANCOVA, $P>0.1$; Table 6). Energy densities of the large group of juvenile sockeye salmon were not significantly affected by location or log length (ANCOVA, $P>0.1$; Table 6).

Tukey HSD tests revealed that Black Lake fish had significantly different energy densities from all other areas in the watershed (Figure 12), that medium sized Black Lake fish are different from other medium sized fish, and that Chignik River and Black Lake small sized fish were significantly different from each other (Figure 13). Table 7 and Figure 14 suggest that within each size group, there were not significant relationships among log lengths and energy densities, as all p-values were greater than 0.1 and r values less than 0.05, but that over the entire size range, there is a significant negative trend between energy density and log length.

Hypothesis 5

H_O: Age 1 sockeye salmon in the Chignik watershed do not exhibit greater energy densities than age 0 sockeye salmon.

Age, length, and weight data were collected from 116 juvenile sockeye salmon.

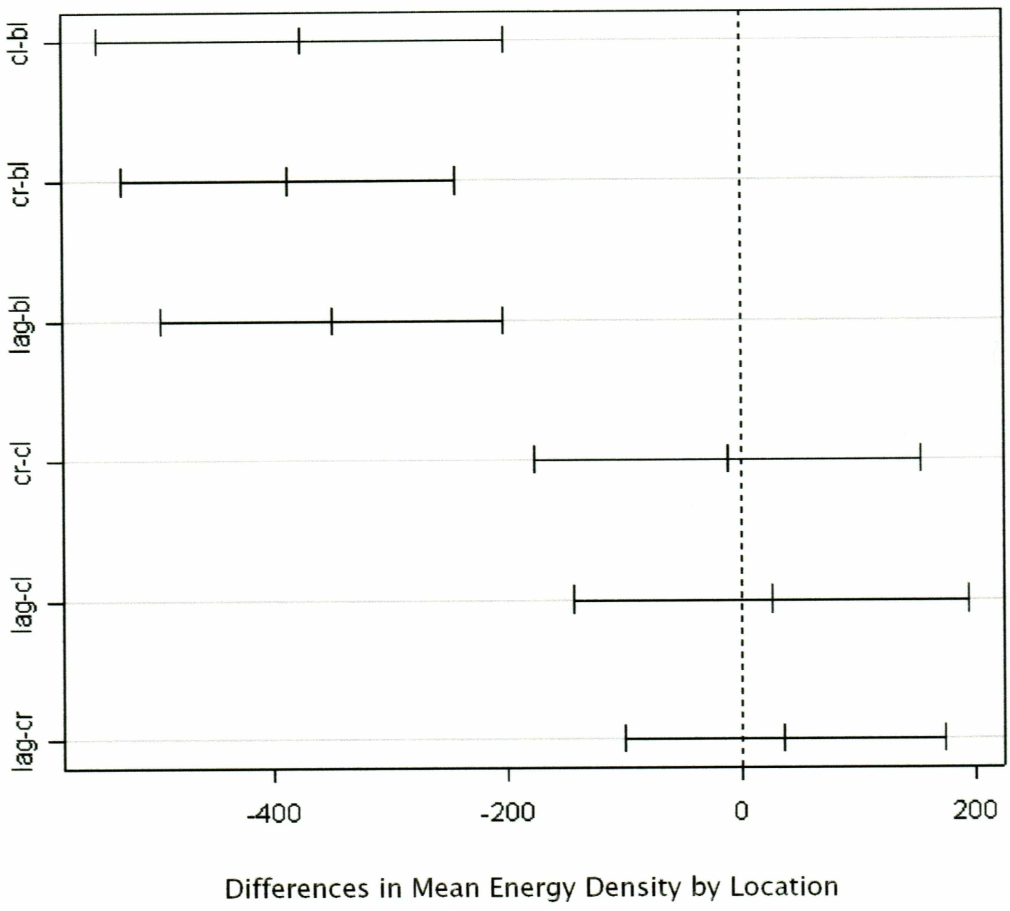

Figure 12. Tukey HSD comparisons of energy density by location of Chignik watershed sockeye salmon, 2002. Confidence intervals are shown at the 95% level. Locations are labeled as bl=Black Lake, cl=Chignik Lake, cr=Chignik River, and lag= Chignik Lagoon.

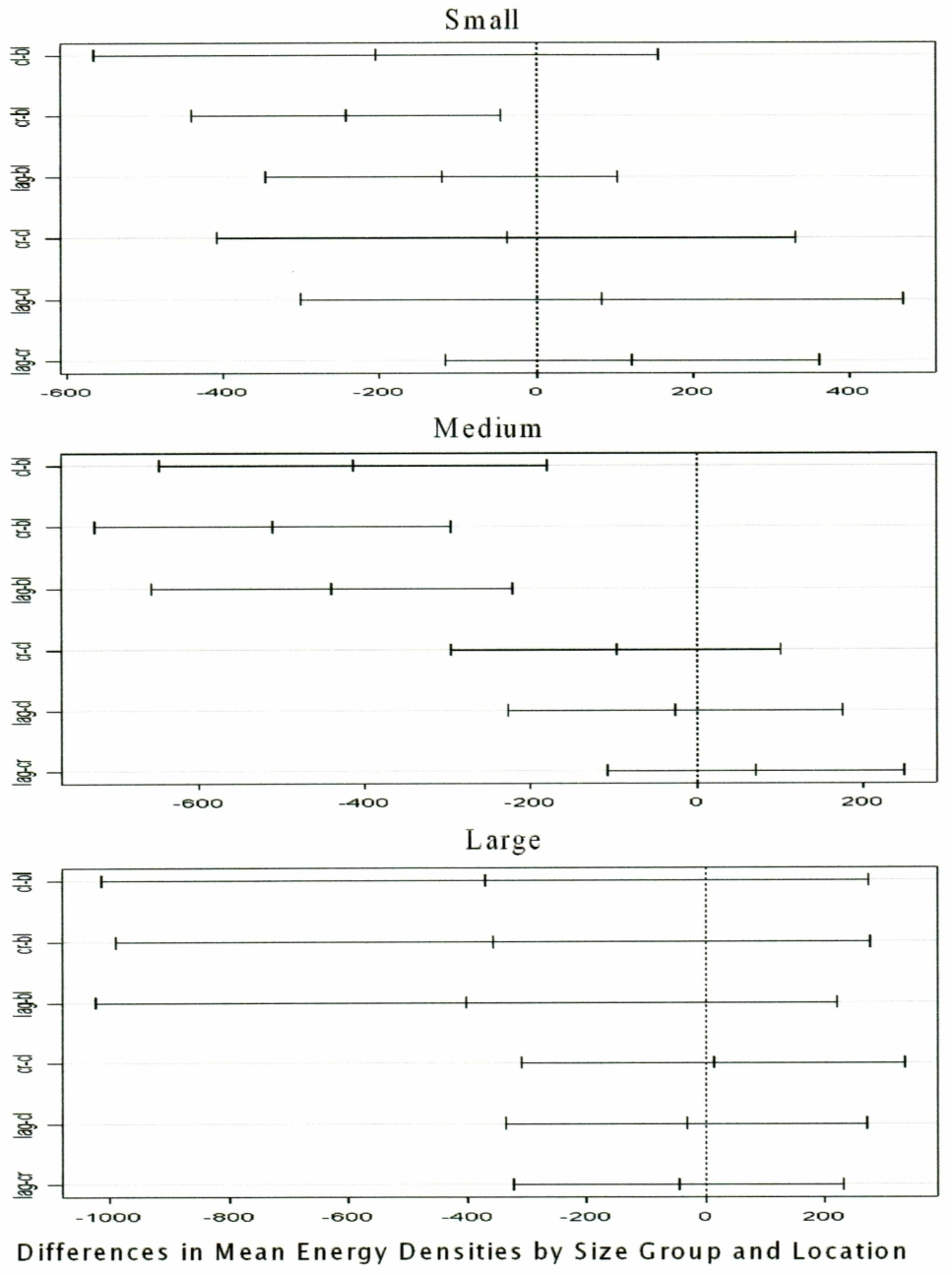

Figure 13. Tukey HSD comparisons of location and energy density by size group of Chignik watershed sockeye salmon, 2002. Confidence intervals are shown at the 95% level. Locations are labeled as bl=Black Lake, cl=Chignik Lake, cr=Chignik River, and lag= Chignik Lagoon.

Table 7. Energy density-log length regression equations by size for the Chignik watershed sockeye salmon, 2002. R-squared, *p*-values, and correlation coefficients are shown. The small size group is less than 46 mm, the medium size group is between 46 and 65 mm, and the large size group is greater than 65 mm.

Independent variable	Regression equation	r	P	Correlation coefficent to energy density
All sizes	Energy Density=7299.1 - 531.5(Log(Length))	0.229	<0.001	-0.478
<46 mm	Energy Density=3284.0 + 563.6(Log(Length))	0.037	0.184	0.193
46 to 65 mm	Energy Density=7298.0 - 540.6(Log(Length))	0.048	0.160	-0.218
>65 mm	Energy Density=6503.6 - 342.0(Log(Length))	0.014	0.567	-0.118

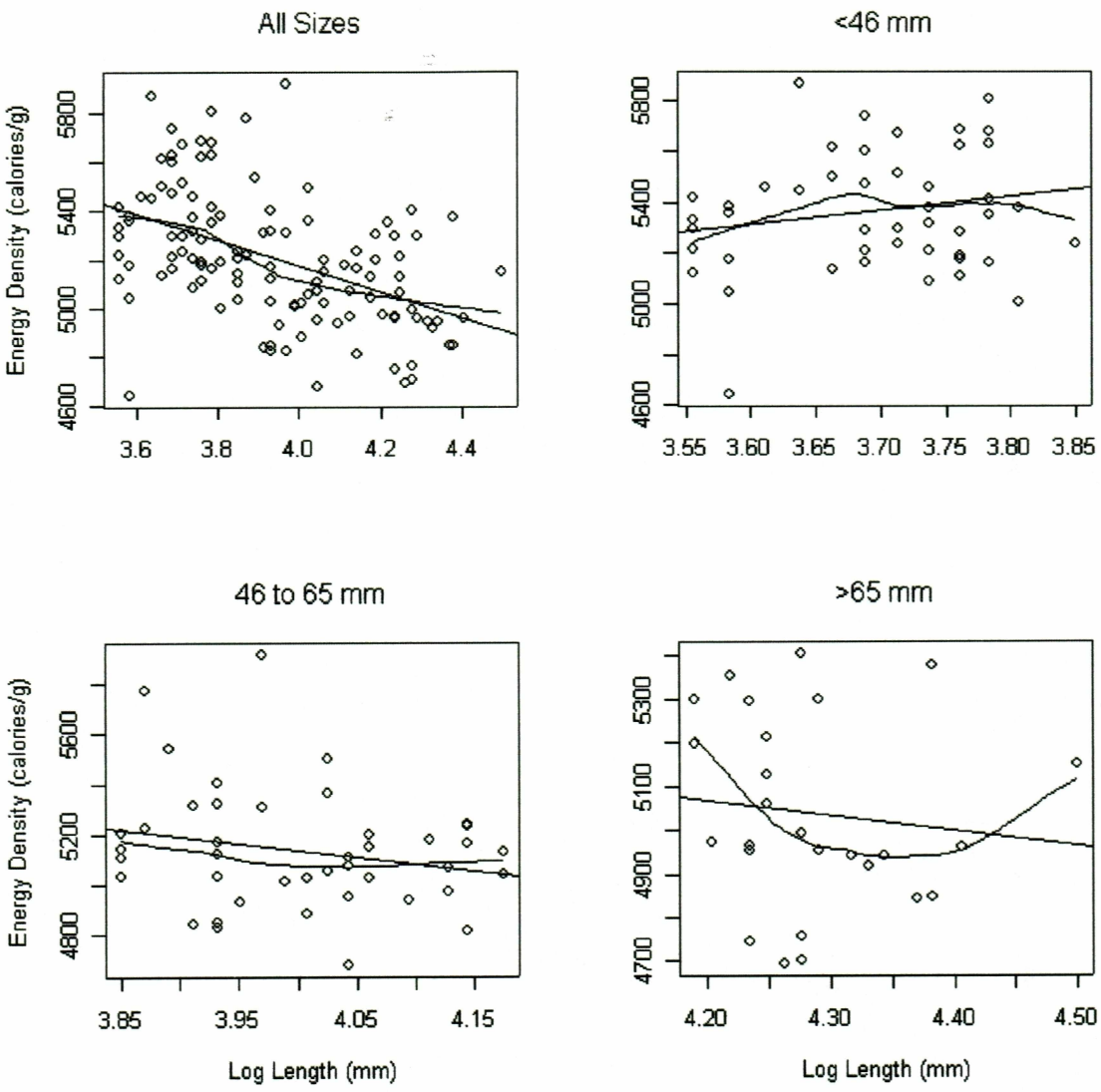

Figure 14. Energy density-log length plots by size of Chignik watershed juvenile sockeye salmon, 2002. All plots are fitted with loess and regression lines. The small size group is less than 46 mm, the medium size group is between 46 and 65 mm, and the large size group is greater than 65 mm.

Of the 118 fish sampled for this study, two fish could not be aged due to illegible scales. Age 0 sockeye salmon throughout the Chignik watershed had significantly greater energy densities than age 1 sockeye salmon (ANOVA, $P<0.001$; Tables 8 and 9). The mean energy densities for age 0 sockeye salmon throughout the watershed were 5,485.14 (SE 48.47), 5,206.63 (SE 53.33), 5,179.84 (SE 39.19), and 5,224.15 cal/g (SE 48.37) for Black Lake, Chignik Lake, Chignik River, and Chignik Lagoon respectively (Figure 14). Age 1 fish averaged 5,048.71 cal/g (SE 68.09) in Chignik Lake, 5,008.91 cal/g (SE 29.39) in Chignik River, and 4,984.19 cal/g (SE 48.76) in Chignik Lagoon (Figure 15). No age 1 sockeye salmon were captured in Black Lake (Figure 15). No significant interaction occurred between location (with factor levels of Chignik Lake, Chignik River, and Chignik Lagoon) and age upon energy density (ANOVA, $P>0.1$; Table 9).

Comparisons of mean energy density, length, and dry weight over the sampling period indicated that Black Lake age 0 sockeye salmon maintained their energy densities over time (Tables 10 and 11). Mean length and dry weight declined after June 22, 2002 but was negative trend was not significant (Tables 10 and 11). Age 0 sockeye salmon were not captured in Chignik Lake until July 3,2002; age 0 fish captured after July 3, 2002 showed significant increases in both mean length and dry weight, but had a similar mean energy density to fish caught earlier in the season in Chignik Lake, which suggests that energy density is affected seasonally in Chignik Lake (Tables 10 and 11). Age 1 sockeye salmon in Chignik Lake showed increases in mean dry weights and energy densities over the season, however, mean length varied over the same time-period (Table 10). Mean energy densities significantly declined in Chignik River age 0 fish after June 14, while mean length and dry weight generally increased over the summer (Tables 10

Table 8. Mean energy density by age for Chignik watershed sockeye salmon, 2002. Standard error is also reported.

	Age 0	Age 1
N	78	38
Mean energy density (calories/g	5,304.81	5,023.66
SE	29.42	28.28

Table 9. Analysis of variance statistics for energy density compared to age and location. All analyses are for juvenile sockeye salmon captured in the Chignik watershed, 2002.

Model	*F*	df	*P*
Age	40.39	1	<0.001
Location	13.41	3	<0.001
Age*Location	0.08	3	0.973

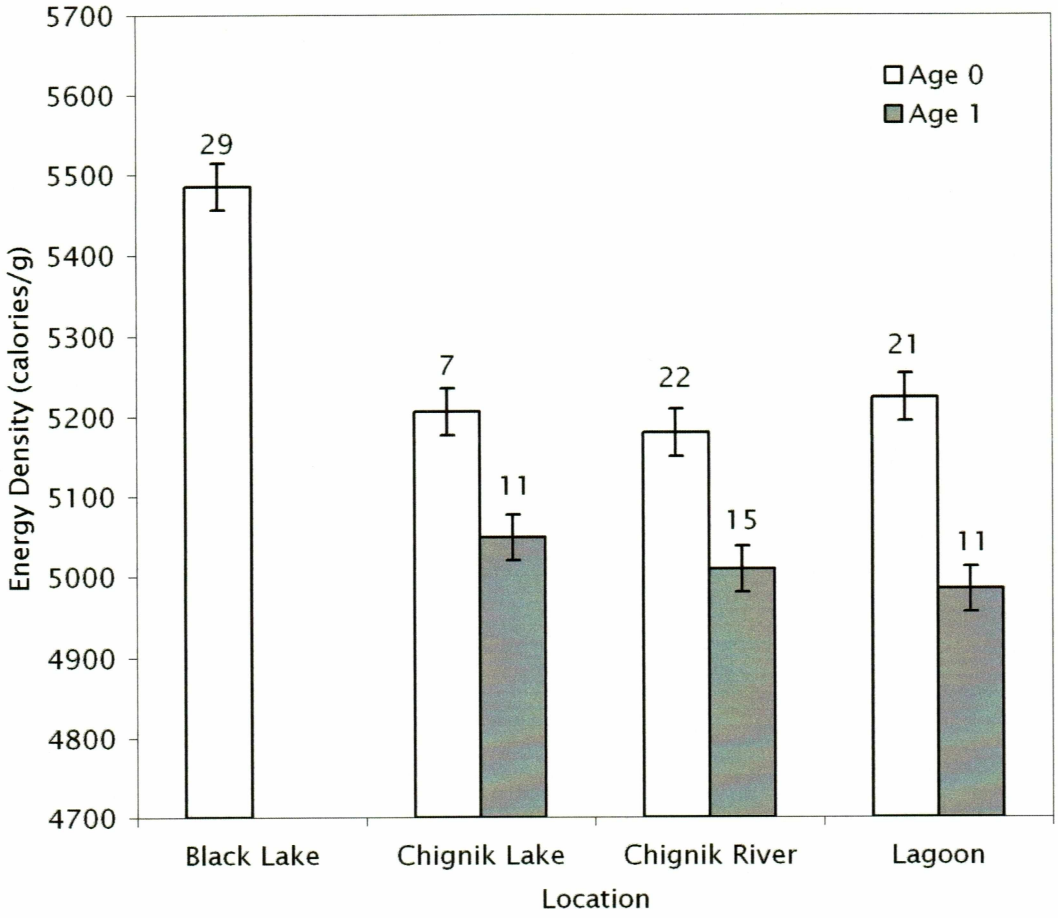

Figure 15. Mean energy density by age and area for Chignik watershed sockeye salmon, 2002. Standard error bars and sample size are also displayed.

Table 10. Mean energy density, length, and dry weight by location and age at the time of sampling for juvenile sockeye salmon captured in the Chignik watershed 2002. Mean surface temperatures, sample sizes and standard errors are also shown.

			Age													
			0							1						
	Sample	Temp		Energy density		Length		Dry weight			Energy density		Length		Dry weight	
Location	date	(°C)	N	(calories/g)	SE	(mm)	SE	(g)	SE	N	(calories/g)	SE	(mm)	SE	(g)	SE
Black Lake	7-Jun	10.8	8	5,334.48	65.31	37.5	0.73	0.043	0.01	NA	NA	NA	NA	NA	NA	NA
	22-Jun	13.7	7	5,480.00	155.92	49.1	4.64	0.222	0.09	NA	NA	NA	NA	NA	NA	NA
	6-Jul	14.1	8	5,584.45	47.24	43.9	1.67	0.102	0.02	NA	NA	NA	NA	NA	NA	NA
	20-Jul	15.2	6	5,559.59	87.29	45.2	1.74	0.100	0.02	NA	NA	NA	NA	NA	NA	NA
Chignik Lake	4-Jun	8.6	NA	NA	NA	NA	NA	NA	NA	2	4,698.16	4.38	71.5	0.50	0.447	0.03
	3-Jul	10.6	4	5,214.59	92.12	41.5	2.47	0.079	0.02	2	5,110.46	41.21	60.0	2.00	0.304	0.02
	18-Jul	11.0	1	5,128.02	NA	65.0	NA	0.524	NA	3	4,951.97	55.57	69.0	5.57	0.561	0.14
	5-Aug	11.8	2	5,230.03	70.95	64.5	1.50	0.449	0.05	4	5,265.67	39.09	66.3	2.69	0.549	0.09
Chignik River	14-Jun	9.0	3	5,372.52	49.63	42.3	0.33	0.073	0.01	4	5,016.48	44.55	62.5	5.61	0.447	0.16
	28-Jun	10.0	5	5,049.89	93.22	47.6	6.82	0.173	0.09	4	4,964.82	59.26	63.8	7.49	0.493	0.19
	13-Jul	11.0	9	5,179.99	49.93	45.4	1.91	0.120	0.02	3	5,076.73	60.83	55.7	1.20	0.237	0.04
	29-Jul	11.3	5	5,193.93	85.00	57.2	7.72	0.337	0.15	4	4,994.56	76.71	55.8	6.26	0.285	0.11
Chignik Lagoon	15-Jun	10.6	6	5,427.71	91.16	44.7	1.63	0.080	0.02	4	4,959.60	128.21	63.0	4.24	0.323	0.08
	29-Jun	11.7	5	5,213.67	65.09	46.0	4.56	0.164	0.07	4	5,017.47	30.46	68.5	3.97	0.550	0.09
	15-Jul	11.5	8	5,162.89	48.36	55.9	5.42	0.380	0.10	2	4,889.07	44.70	69.5	9.50	0.516	0.17
	30-Jul	12.3	2	4,884.68	63.11	54.0	3.00	0.245	0.04	1	5,139.70	NA	47.0	NA	0.137	NA

Table 11. Analysis of covariance statistics for energy density compared to date and log length by location. All analyses are for juvenile sockeye salmon captured in the Chignik watershed, 2002.

Model	*F*	df	*P*
Black Lake			
Date	1.56	3	0.229
Log length	0.53	1	0.477
Date*Log length	1.39	3	0.274
Chignik Lake			
Date	18.44	3	<0.001
Log length	5.52	1	0.047
Date*Log length	1.43	3	0.290
Chignik River			
Date	2.79	3	0.016
Log length	6.83	1	0.014
Date*Log length	2.09	3	0.123
Chignik Lagoon			
Date	2.01	3	0.137
Log length	28.67	1	<0.001
Date*Log length	1.69	3	0.193

and 11). Chignik River age 1 fish maintained their energy densities over the summer on average, however, both mean length and dry weight declined midway through the sampling season (Table 10). Mean length and dry weight generally increased over the summer, while mean energy densities declined in Chignik Lagoon age 0 sockeye salmon; but, these fluctuations were affected by fish size and not the sample date (Tables 10 and 11). Chignik Lagoon age 1 fish showed increases in both mean weight and length until July 15, 2002, after which time their mean length and dry weight decreased; mean energy densities remained at consistent levels over the sampling period (Tables 10 and 11).

Hypothesis 6

H_O: Energy densities of juvenile sockeye salmon of similar length, which are captured in each of the four rearing areas of the Chignik watershed, are not correlated with the temperature in each of the four respective rearing areas in the Chignik watershed.

Thermograph data from the summer of 2002 in both lakes indicated that Black Lake (1 m depth) was continually warmer than Chignik Lake by roughly 3.0 °C and between the depths of 1 m and 29 m in Chignik Lake there was a 0.7 °C temperature difference (Figure 16) on average. Chignik Lake temperature-depth profiles indicated temperature gradient in June, 2002, however, in July and August, 2002, water temperatures remained homogenous to a depth of approximately 20 m (Figure 17). Water temperatures at depth in Black Lake remained fairly homogenous throughout the water column during the times of temperature profiling (Figure 18). Surface and depth profiled

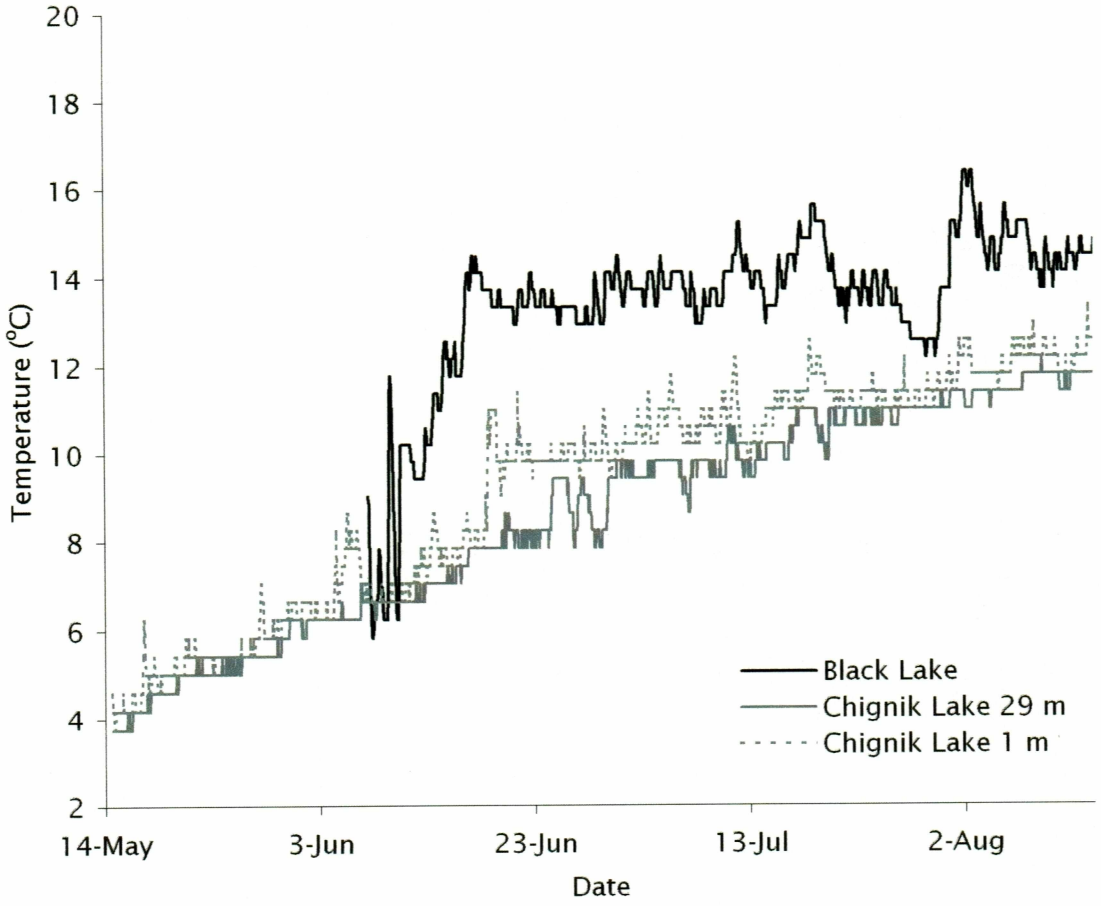

Figure 16. Thermograph data from Black Lake (1 m), and Chignik Lake (1 m and 29 m), 2002. The Black Lake temperature fluctuations at the end of the sampling period was due to the lag between retrieving the thermograph and downloading the data.

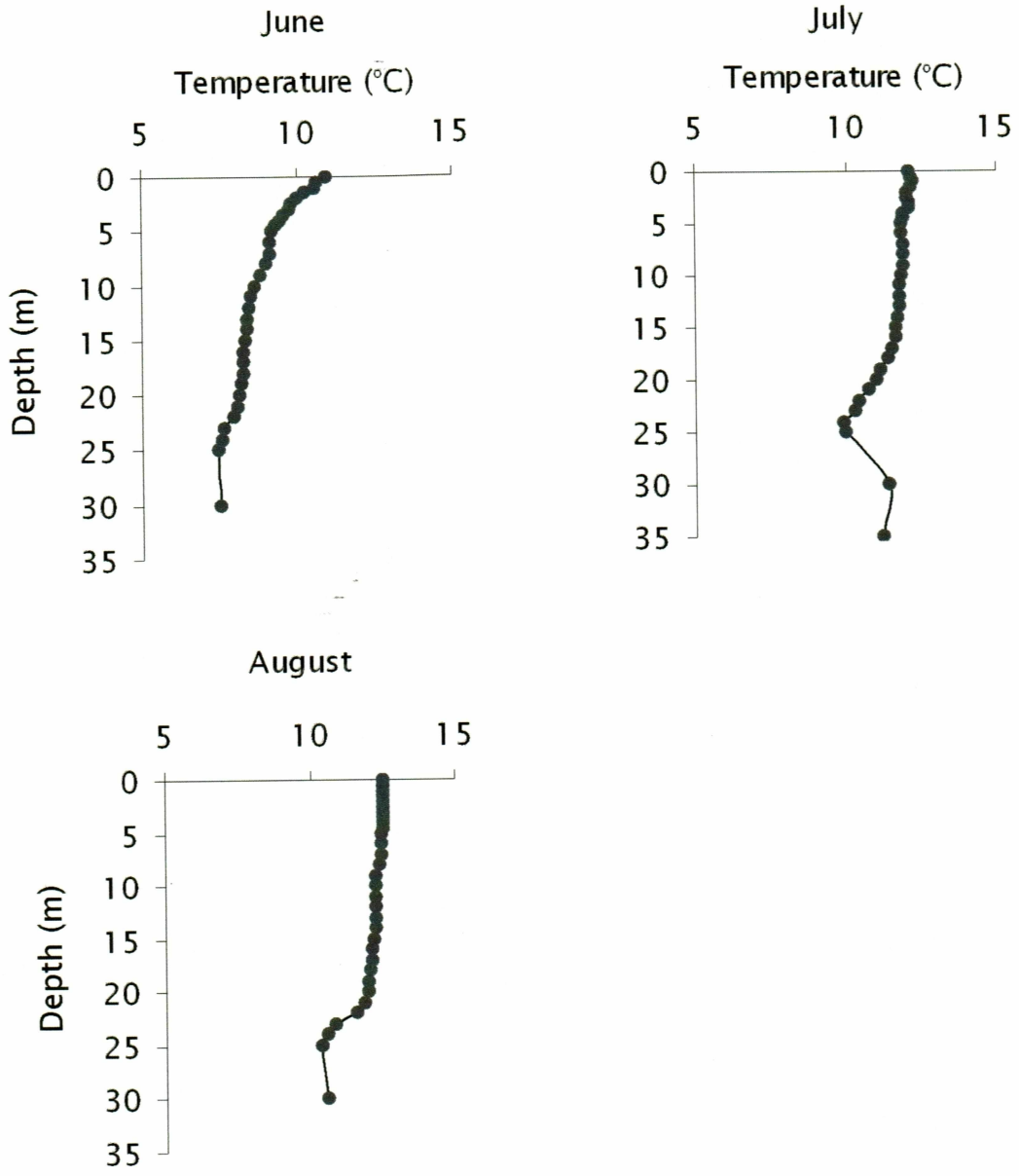

Figure 17. Mean monthly temperature profiles for Chignik Lake, 2002.

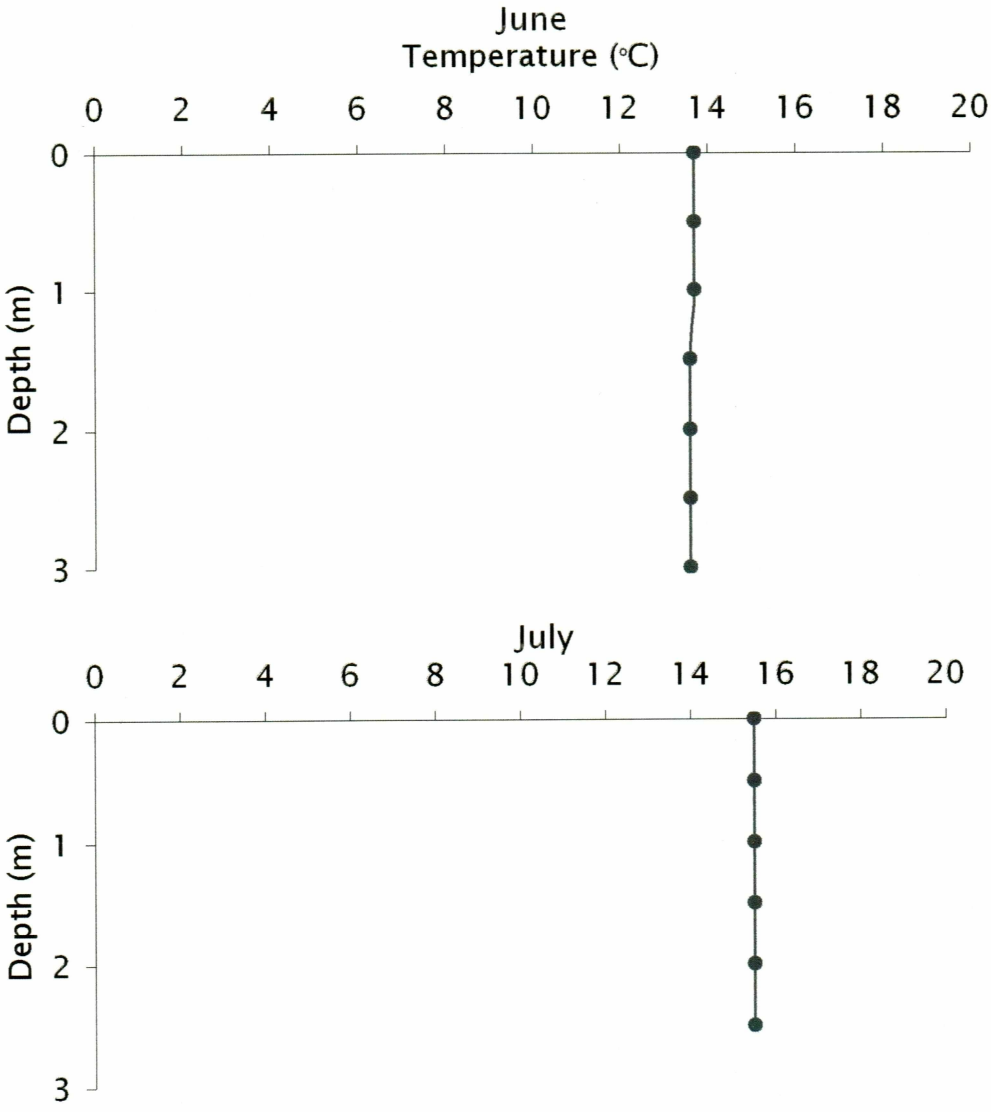

Figure 18. Mean monthly temperature profiles for Black Lake, 2002.

temperatures among sites within each location (Figure 19) varied minimally in Black Lake, Chignik River, and Chignik Lagoon indicating homogenous temperatures within those portions of the watershed. The temperatures of the different sites in Chignik Lake varied 3.0 °C on average among each other (Figure 19). Chignik Lake site seven had a temperature spike of 13.0 °C, which was attributed to measurement error, and thus was not included in statistical analyses (Figure 19). A one- way ANOVA comparing the temperatures of each location to one another indicated significant differences in surface temperature among some locations (F=28.065, df =3, 115, P<0.001). A Tukey HSD test revealed that Black Lake and Chignik Lagoon were not significantly different from each other, but had significantly warmer temperatures than both Chignik Lake and Chignik River (Figure 20). Chignik Lake and Chignik River did have not significantly different surface temperatures (Figure 20). This indicates that Chignik Lake and Chignik River are colder rearing environments than either Chignik Lagoon or Black Lake.

Black Lake's mean surface temperature was warmer than Chignik Lake and Chignik River mean surface temperatures, but was comparable to Chignik Lagoon mean surface temperatures (Figure 21). Chignik River had the coldest temperatures in the watershed during the 2002 sampling period (Figure 21). On average, juvenile sockeye salmon captured in Black Lake fell into the small size group and had greater energy densities than fish captured in other locations (Figure 21). Juvenile sockeye salmon captured in the lower portions of the watershed were in the medium size group and had comparable energy densities (Figure 21). A full model, comparing temperature, location and size to energy density for all fish revealed no interactions among factors, however, each factor on its own did have a significant relationship with energy density (all single

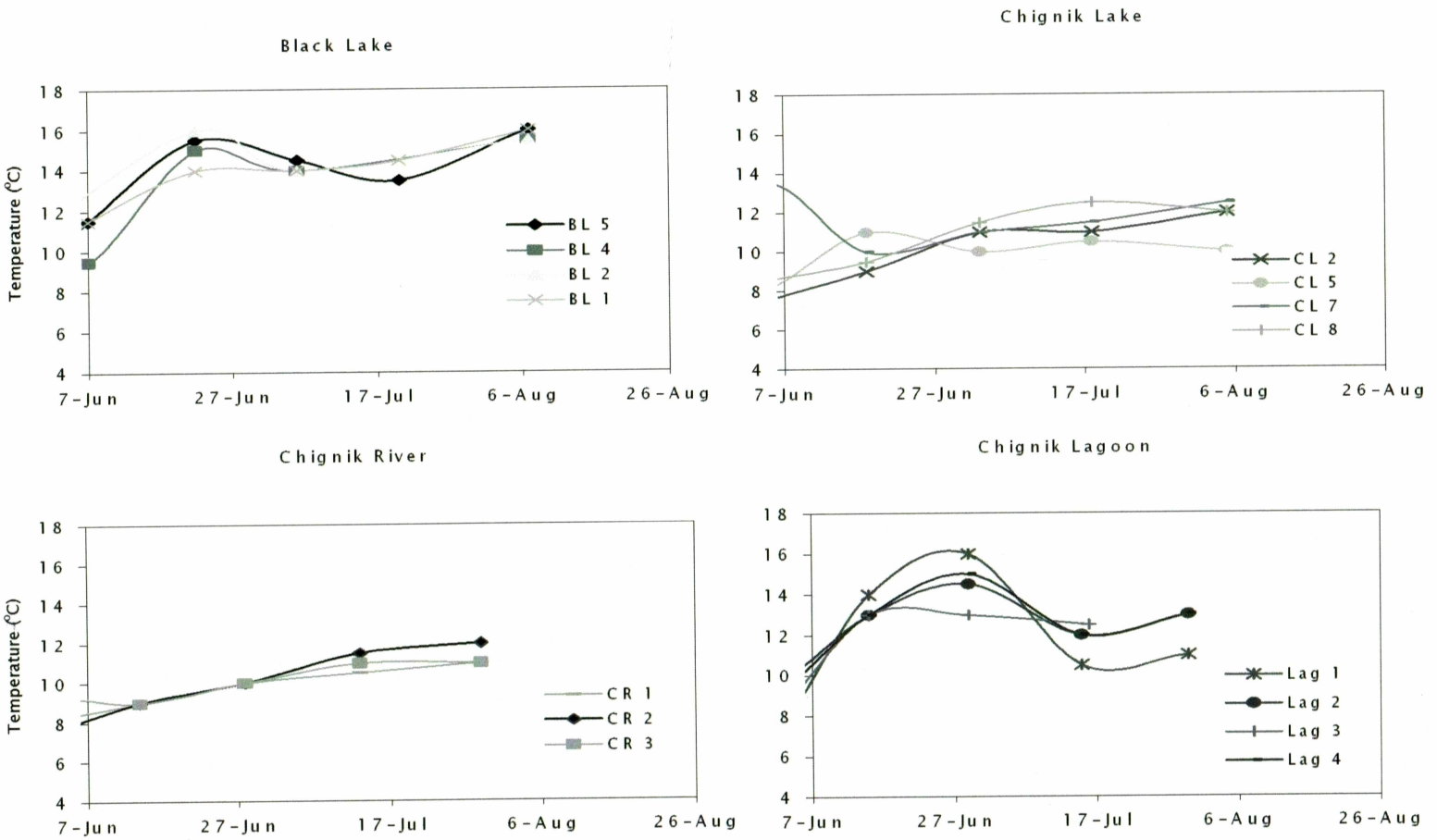

Figure 19. Surface temperatures of sites in the Chignik watershed, 2002. Legend notation shows each location sampling sites

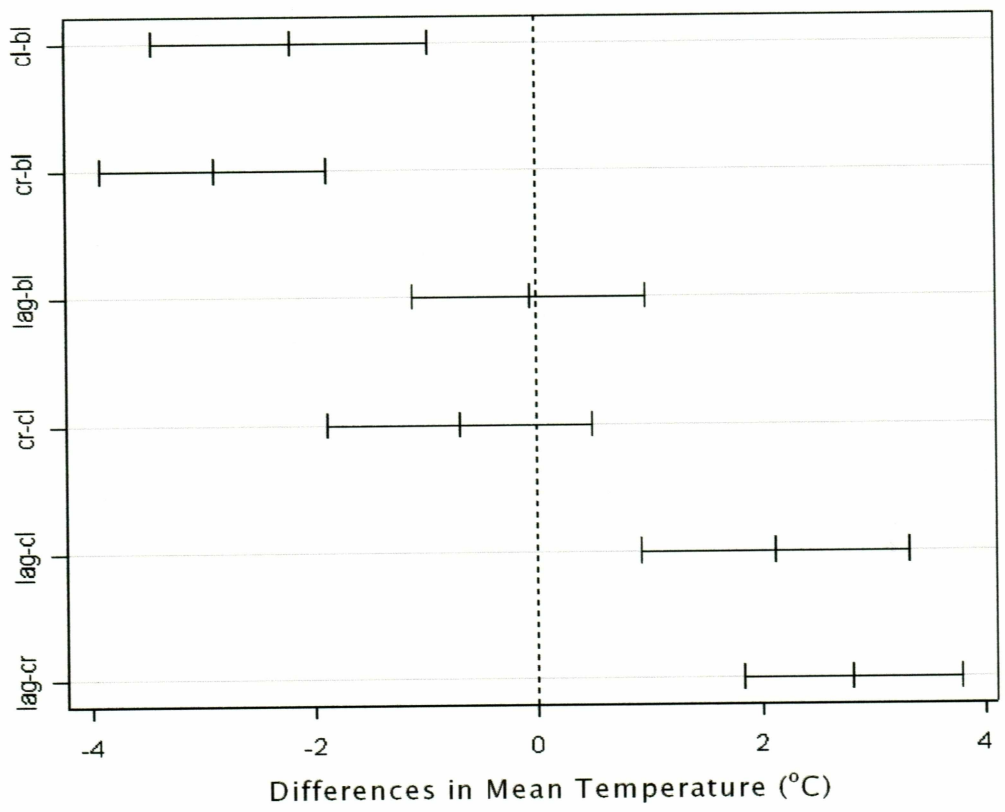

Figure 20. Tukey HSD comparisons for temperature and location. Confidence intervals are shown at the 95% level. Locations are labeled as bl=Black Lake, cl=Chignik Lake, cr=Chignik River, and lag= Chignik Lagoon.

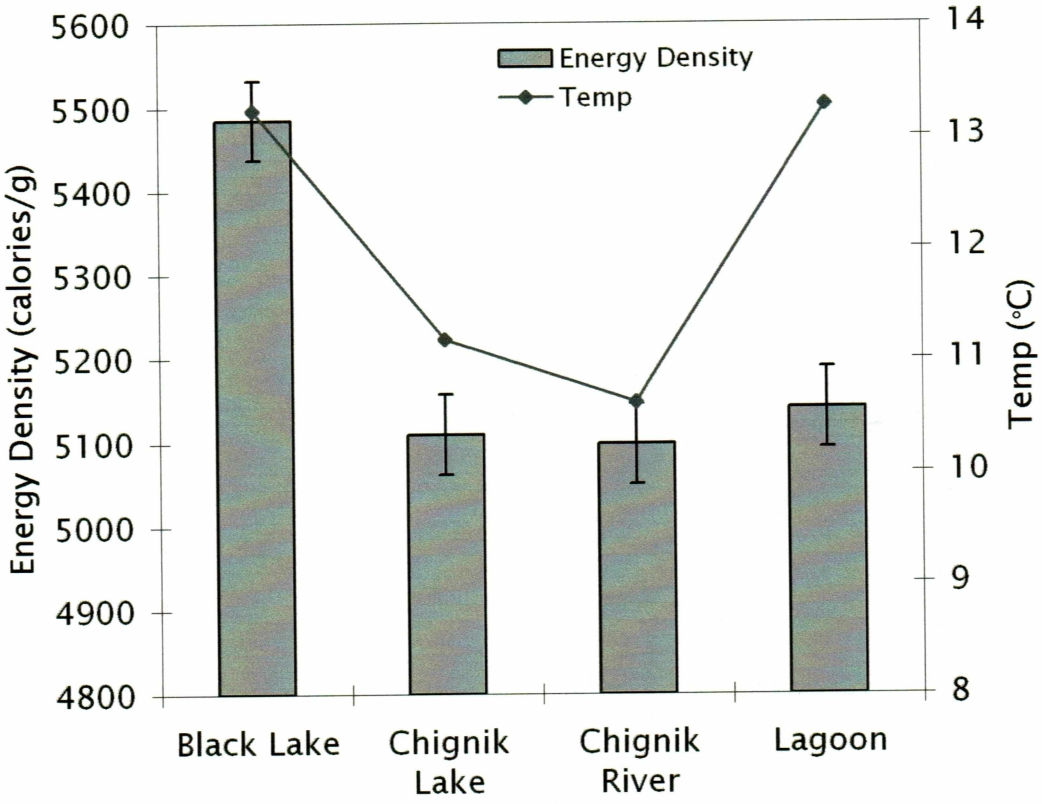

Figure 21. Mean energy density and temperature by location for Chignik watershed juvenile sockeye salmon, 2002. Standard error bars for energy density are also shown.

factor $P<0.025$; Table 12). Comparisons of temperature and location to energy density by size group yielded different results (Table 13). For small juvenile sockeye salmon, temperature was a significant factor in explaining energy density (ANCOVA, $P<0.01$; Table 13). There were no other significant relationships (Table 13) indicating that temperature affects the caloric content of a small fish regardless of where it might rear. For juvenile sockeye salmon in the medium group, temperature was also significant (ANCOVA, $P<0.001$; Table 13) as was location factors were significant (ANCOVA, $P>0.1$; Table 13). This would suggest sufficient variability in the energy densities of large juvenile sockeye salmon, which cannot be attributed to location or temperature.

Linear regression plots of temperature and energy density (Table 14, Figure 22) indicate significant relationships ($P<0.01$) among temperature and energy density for all groups except the large size group, however, the relationships are poorly explained by the regression model. A wide range of caloric values can be found over the given temperature range (Figure 22). The temperature against log length plots (Table 15, Figure 23) further demonstrates the poor linear relationship between these variables ($r<0.09$); a variety of lengths occur at a given temperature range.

Referring back to Table 10, Black Lake age 0 juvenile sockeye salmon increased or maintained their mean energy density levels with increasing mean temperatures over the sampling period. Age 0 fish in the other three locations either maintained or age 0 fish experienced declines in mean length and dry weight after the lake surface temperature exceeded 13.7 °C, whereas age 0 fish from Chignik Lake, Chignik River, and Chignik Lagoon had positive increases in mean length and dry weight (Table 10). However, mean surface temperatures in the lower three rearing areas did not exceed 12.3 °C

Table 12. Analysis of covariance statistics for energy density compared to temperature, size, and location. All analyses are for juvenile sockeye salmon captured in the Chignik watershed, 2002.

Model	*F*	df	*P*
Temperature	5.11	1	0.026
Size	12.63	2	<0.001
Location	8.99	3	<0.001
Size*location	0.82	6	0.557
Temperature*location	2.18	3	0.154
Temperature*size	2.16	2	0.120
Temperature*size*location	1.71	4	0.155

Table 13. Analysis of covariance statistics for energy density compared to temperature and location. All analyses are for juvenile sockeye salmon captured in the Chignik watershed, 2002.

Model		*F*	df	*P*
Small fish				
	Temperature	9.00	1	0.005
	Location	2.16	3	0.107
	Temperature*location	2.97	2	0.062
Medium fish				
	Temperature	28.18	1	<0.001
	Location	7.53	3	0.001
	Temperature*location	1.42	3	0.253
Large fish				
	Temperature	0.25	1	0.876
	Location	1.22	3	0.330
	Temperature*location	1.45	2	0.260

Table 14. Energy density-temperature regression equations for Chignik watershed sockeye salmon, 2002. R-squared, p-values, and correlation coefficients are shown.

Independent variable	Regression equation	r	P	Correlation coefficient to energy density
All sizes	Energy density=4679.6 + 43.5(Temp)	0.109	<0.001	0.329
<46 mm	Energy density=4857.9 + 41.7(Temp)	0.142	0.007	0.377
46 to 65 mm	Energy density=4315.6 + 68.8(Temp)	0.313	<0.001	0.559
>65 mm	Energy density=5076.7 - 3.2(Temp)	9.8E-04	0.880	-0.031

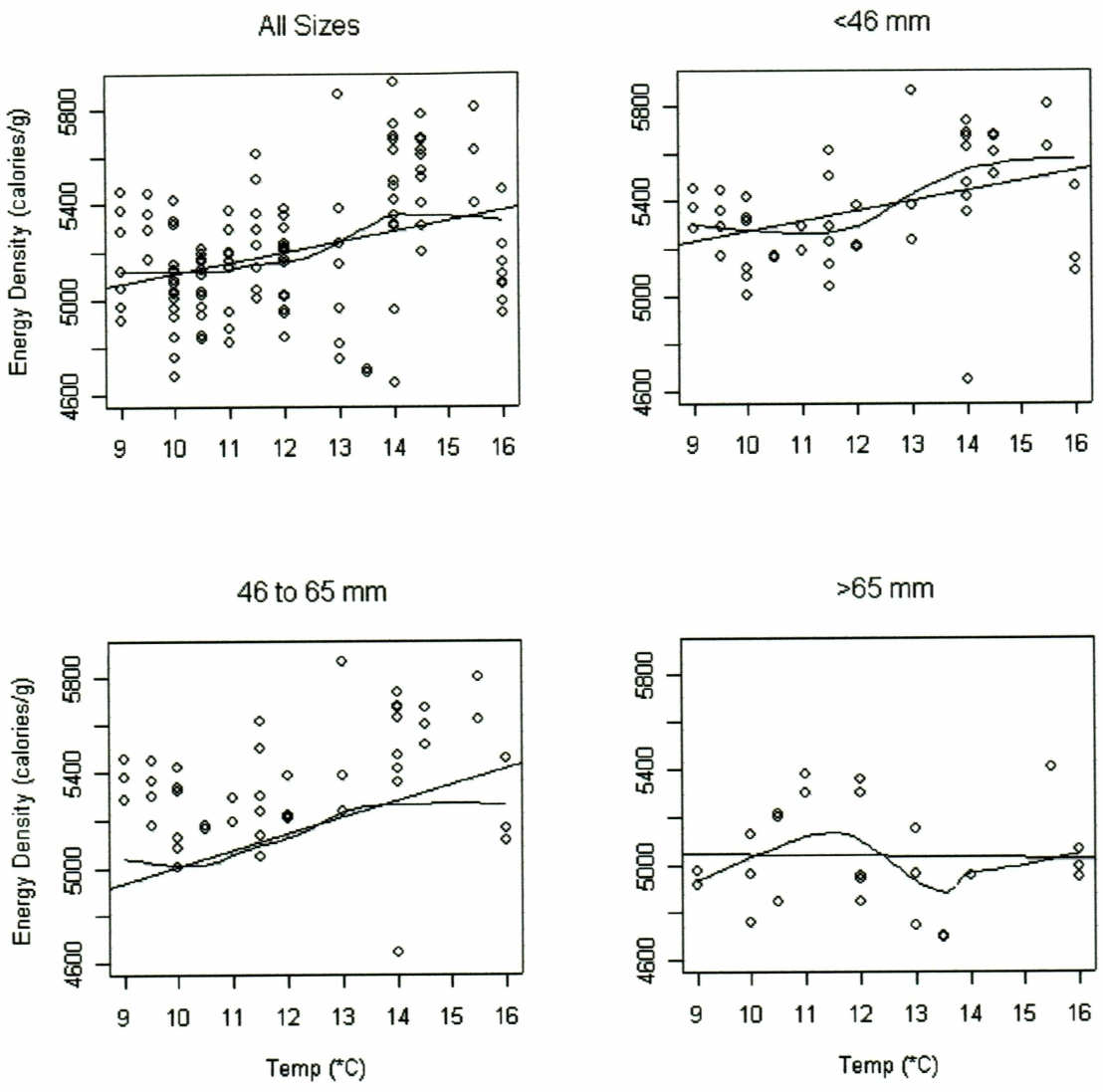

Figure 22. Energy density-temperature plots by size for the Chignik watershed sockeye salmon, 2002. All temperatures are from sampling sites. All plots are fitted with loess and regression lines. The small size group is less than 46 mm, the medium size group is between 46 and 65 mm, and the large size group is greater than 65 mm.

Table 15. Temperature-log length regression equations for Chignik watershed sockeye salmon, 2002. R-squared, p-values, and correlation coefficients are shown.

Independent variable	Regression equation	r	P	Correlation coefficient to log length
All sizes	Log(Length)=4.0 - 0.0014(Temp)	1.3E-04	0.901	-0.011
<46 mm	Log(Length)=3.6 + 0.0111(Temp)	0.085	0.048	0.292
46 to 65 mm	Log(Length)=4.1 - 0.0093(Temp)	0.035	0.221	-0.188
>65 mm	Log(Length)=4.3 - 0.0015(Temp)	0.002	0.833	-0.043

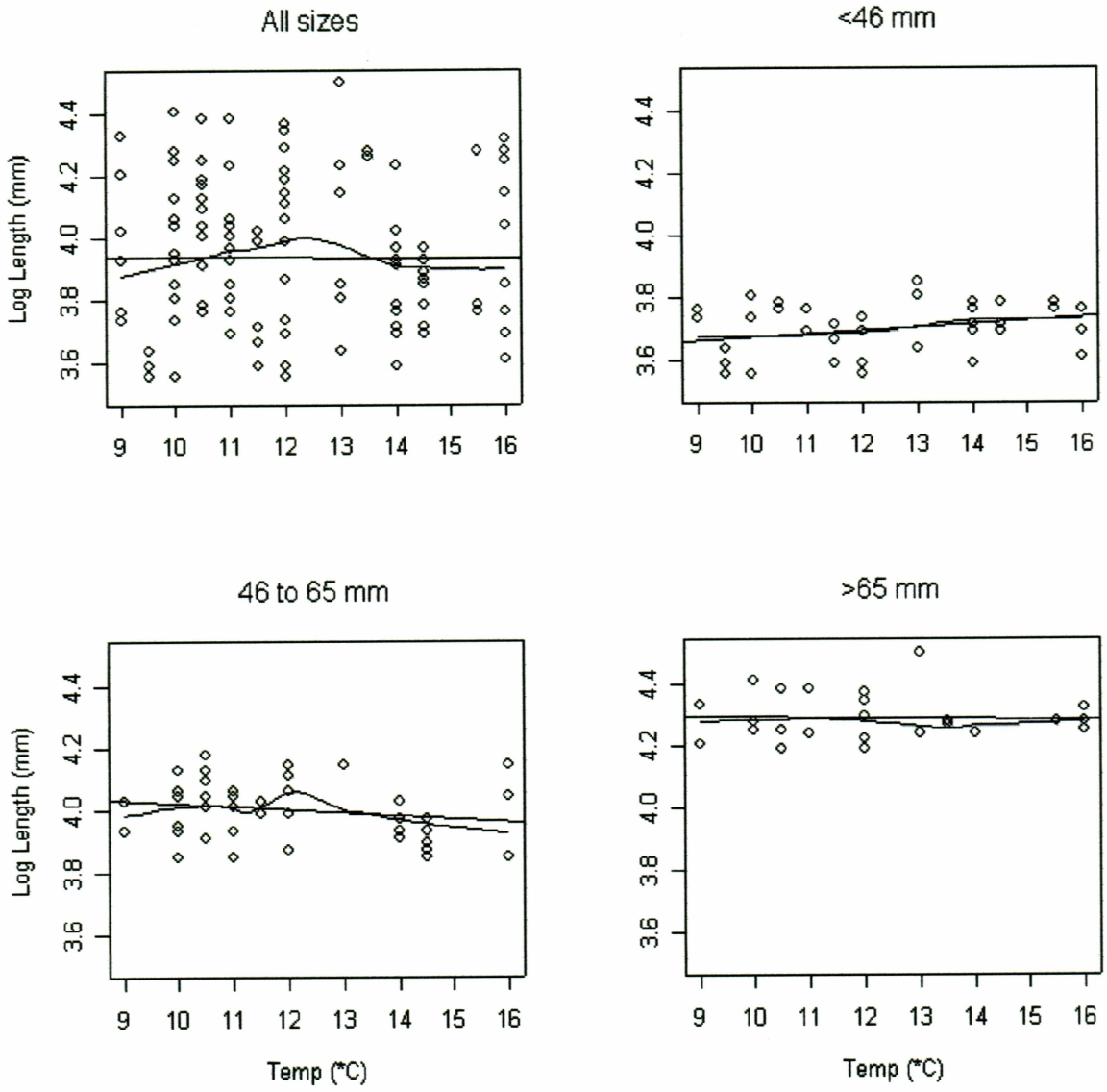

Figure 23. Log length-temperature plots by size groups of the Chignik watershed sockeye salmon, 2002. All plots are fitted with loess and regression lines. The small size group is less than 46 mm, the medium size group is between 46 and 65 mm, and the large size group is greater than 65 mm.

experienced declines in mean energy density (Table 10). In contrast, Black Lake during the sampling period (Table 10). Mean energy densities and dry weights of Chignik Lake age 1 sockeye salmon generally increased with increasing temperature. However, mean lengths fluctuated with an increase in mean temperatures. Despite having mean surface temperatures similar to Chignik Lake, Chignik River age 1 sockeye salmon maintained relatively low mean energy densities and experienced mid-season declines in mean lengths and dry weights concurrent with increasing mean temperatures (Table 10). Chignik Lagoon age 1 sockeye salmon had increases in mean length and dry weight with increasing temperatures until July 30, 2002; mean energy densities remained relatively similar under the same temperature conditions (Table 10).

Discussion

Juvenile sockeye salmon in the Chignik watershed experience constraints in their rearing environment; reduced zooplankton forage bases (Kyle 1992; Bouwens and Finkle 2003), density dependence (Narver 1966; Parr 1972), excessively warm temperatures in Black Lake (Bouwens and Finkle 2003), and reduced rearing area in Black Lake (Ruggerone et al. 1999) have been reported as affecting migratory trends, condition, or growth. The effects of these constraints on Chignik watershed fish can be assessed with length-weight data, condition indices, growth rates, and energetic data (Anderson and Gutreuter 1983). While the validity of condition indices is often questionable (Broekhuizen et al. 1994), growth rate data paired with energy density data, however, may provide a lucid picture of the life history strategies of Chignik watershed juvenile sockeye salmon (Brett et al. 1969; Brett 1971).

Fulton's condition factor data are currently employed by the ADF&G to interannually compare juvenile sockeye salmon health in the Chignik watershed (Bouwens and Finkle 2002). This isometric assessment of growth often does not apply to rearing juvenile fish, however, because they grow in stanzas (Bagenal 1978; Broekhuizen et al. 1994). In the present study juvenile sockeye salmon growth in the Chignik watershed was fitted better with the allometric relative condition factor model as opposed to the isometric Fulton's Condition factor model. It has been shown that change in one variable does not always accurately reflect the change in another. Specifically, the simple log-linear relationship between length and weight does not necessarily reflect fish health (Broekhuizen et al. 1994).

Parameter estimation with a relative condition factor model resulted in a larger correlation with energy density but was not statistically significant. The variation associated with the length and weight data may affect the accuracy of condition factor data of the Chignik watershed juvenile sockeye salmon. Le Cren (1951) and Bagenal (1978) have noted that weight data are subject to measurement error more than length data. Additionally, weight can misrepresent the condition of a fish via its constituents; if a fish's mass is comprised of more water than protein or fat, which suggests a reduction in energy available for growth or maintenance, condition would be overestimated (Brett et al. 1969). For Chignik watershed fish, energy density data were poorly explained by weight and length linear regressions, and condition factor, which suggest that the methods of estimating fish health should be reassessed (Kesteven 1947).

Comparisons of length and dry weight to energy density of Chignik watershed juvenile sockeye salmon indicated that there were significant relationships among these

variables. However, the variability in energy density was not adequately explained by linear relationships. These findings are not surprising as weight data are subject to a multiplicative error structure and allometric effects (Hewett and Kraft 1993).

Energy density compared to age and by size group proved more revealing than to length and weight alone. Sockeye salmon in the small group throughout the watershed had significantly greater energy densities than larger fish. Similarly, age 0 fish had greater energy densities than age 1 fish. Large fish may have higher maintenance costs than small fish because of smoltification, regardless of age. Additionally, they may still be in an energy deficit from overwintering (in the case of age 1 fish; Doble and Eggers 1978; Metcalfe and Thorpe 1992; Forseth at al. 1994). Similarly, it may be the life history strategy of the small fish to acquire relatively large energy stores before their first winter (Forseth et al. 1994).

Other facets of the energy density differences among size groups of juvenile sockeye salmon in the Chignik watershed may be attributed to their age and rearing location. Black Lake fish, which fall predominantly between the small and medium size groups, had significantly higher energy densities than fish in all other parts of the watershed. Medium-sized Black Lake sockeye salmon had the highest energy densities of any size group in any location. It should also be noted that all Black Lake juvenile sockeye salmon are age 0 (Ruggerone et al. 1999; Bouwens and Finkle 2003). Similarly, all age 0 sockeye salmon had significantly greater energy densities than age 1 sockeye salmon throughout the watershed. These data can infer several conclusions, however, they require thorough explanation.

Smaller fish have higher metabolic demands based on surface area to volume

ratios, and therefore are more susceptible to depleting their lipid stores faster than larger fish (Elliott and Persson 1978; Sogard and Olla 2000). Ration type and size are also considered a major influence on fish health and energetic levels (Brett et al. 1969; Elliott 1975; Doble and Eggers 1978; Arrhenius and Hansson 1994). Because Black Lake fish are smaller and maintain higher energy densities than rearing sockeye salmon in the other locations of the watershed, this suggests that Black Lake is a better rearing environment for age 0 fish than the other areas of the watershed. The shallow nature of Black Lake is of particular importance because it virtually renders the entire lake to be a littoral zone, very suitable for aquatic insect habitation (Parr 1972). Black Lake juvenile sockeye salmon had an equal abundance of zooplankton and insect prey items in their digestive tracts (Bouwens and Finkle 2003). By dry weight, however, chironomid larvae comprised the majority of prey items found in Black Lake juvenile sockeye salmon digestive tracts (Parr 1972; Bouwens and Finkle 2003). Wissing and Hasler (1971) determined that the energetic content of chironomid larvae (between 5,320 and 6,412 calories/g dry weight) was greater than that of zooplankton (*Daphnia* sp. = 4,170 to 4,993 calories/g dry weight), which suggests that chironomid larvae are calorie-rich forage compared to zooplankton. Black Lake also maintained greater cladoceran zooplankton abundance, which are considered the preferred food of juvenile sockeye salmon (Kyle 1992), than Chignik Lake during the 2002 summer study period (Bouwens and Finkle 2003). However, if the type and availability of forage is favorable for rearing Black Lake sockeye salmon, why then, is there only an age 0 zero component of the Black Lake stock? Why would these fish choose to leave an area of abundant forage and abandon potential growth opportunities?

Several studies (Narver 1966; Parr 1972; Ruggerone et al. 1999) have reported that Black Lake juvenile sockeye salmon migrate downstream in the watershed during the mid to late summer months to avoid overwintering in Black Lake. Ruggerone et al. (1999) stated that when Black Lake freezes, it does not meet the oxygen demands of overwintering sockeye salmon because of the morphological changes to the lake. Narver (1966) indicated that density dependent effects regulated the migration of Black Lake juvenile sockeye salmon to Chignik Lake. In support of this, although the zooplankton abundance in Black Lake is greater than in Chignik Lake (Table A-1; Table A-2), their size, and thus their biomass, is smaller in Black Lake (Table A-3; Table A-4; Table A-5; Table A-6). The cladoceran *Bosmina,* which is the most abundant Black Lake zooplankton species, reproduces at small sizes when subject to heavy grazing pressure (Kyle 1992). As juvenile sockeye salmon have an elective feeding size threshold >0.4 mm (Kyle 1992) and the Black Lake cladocera size was <0.37 mm on average (Table A-5), this would suggest top-down pressures on the cladoceran population. The low abundance of predatory adult copepods would also suggest top-down grazing pressures (Table A-1). This is despite the additional forage of chironomid larvae (Finkle and Bouwens 2001; Bouwens and Finkle 2003).

Top-down grazing pressure in Black Lake may be the result of interspecific and intraspecific competition. Pond smelt, threespine stickleback, and ninespine stickleback are common in Black Lake (Table A-7). It has been suggested that pond smelt influence the biomass, thus growth, of juvenile sockeye salmon in Black Lake more than the other rearing species (Narver 1966). Unlike sticklebacks, which consume benthic forage in addition to zooplankton, pond smelt feed mainly on zooplankton, increasing the

competition for the preferred sockeye salmon forage (Narver 1966; Doble and Eggers 1978). The shallow depth of Black Lake may force sockeye salmon and pond smelt to share the same forage base and feeding locations as they cannot vertically migrate in the water column to different depths, at different times (Narver 1966; Eggers 1978). This dietary overlap of Black Lake fishes was reflected by changes in biomass (Narver 1966).

The availability of chironomid larvae as juvenile sockeye salmon forage may also be significant to the outmigration of fish from Black Lake. Field observations from the ADF&G ecological assessment have noted that chironomid larvae in Black Lake begin their hatch and leave the water column in July. This hatch timing, and thus loss of available forage for rearing fish, also coincides with the downstream movement of Black Lake fish. However, it is uncertain if these factors act as migratory cues. These factors may only partially contribute to the Black Lake sockeye salmon migration.

Predation, either avian or piscivorous, as a factor influencing migration from Black Lake seems unlikely. The turbidity and aquatic vegetation of Black Lake can provide refuge from visual predators and the abundances of coho salmon and Dolly Varden (*Salvelinus malma*) are relatively low in comparison to sockeye salmon (Table A-7; Eggers 1978). From a bioenergetic perspective, however, other explanations for the mid season migration of Black Lake fish are also quite plausible.

Energetic data and growth rates have often been compared to ration size and temperature to indicate optimal rearing environments for fish (Brett et al. 1969; Elliot 1975; Brett 1976). Brett has reported an optimal freshwater temperature for growth in juvenile sockeye salmon to be 15 °C when fed a maximum ration (1969). Thermograph data from Black Lake indicated that temperatures began to exceed 15 °C on July 17, 2002

and continued to increase through the remainder of the summer. Comparisons of the mean energy densities of Black Lake juvenile sockeye salmon over the 2002 sampling season indicated that, although still positive, the general rate of increase declined with increasing temperature. This supports that high rearing temperatures prevent energy storage and acquisition and subsequently decrease the energy available for growth, if the available ration cannot meet increasing metabolic maintenance costs such as respiration, excretion, assimilation, and thermoregulation (Brett et al. 1969; Elliott 1976). For Black Lake fish, which had significant relationships between temperature and energy density, it can be inferred that the warmer temperatures diverted energy originally allocated to growth towards maintenance functions instead. The ongoing ADF&G ecological assessment, which gathered digestive tract data from one in every five juvenile sockeye salmon collected during the 2002 sampling season, also supports this. Digestive tract fullness, defined as the percentage of weight that the digestive tract contributes to the total fish body weight, and prey composition were determined for all samples (Bouwens and Finkle 2003). From the ADF&G study, digestive tract fullness (Table A-8) declined from 21.1% to 13.5% between June 22, 2002 and July 13, 2002, which suggests that the Black Lake fish were unable to acquire the ration size necessary to maintain their previous growth rate and support maintenance demands at the higher temperature levels.

Additionally, the shallow nature of the Black Lake prevents thermocline formation in the water column and abnegates vertical migration of juvenile sockeye salmon from the high temperatures as shown by fishes exposed to similar conditions in other studies (Sogard and Olla 2000; Morgan and Metcalfe 2001). Chignik Lake, because it is colder than Black Lake and possesses a mild temperature gradient over depth, can

provide refugia via vertical migration from the warm and energetically taxing temperatures of Black Lake, while providing a similar forage base (Table A-9). The combined effects of increasing temperature and competition, as evidenced by changes in energy density and reduced stomach fullness and zooplankton size, might be responsible for the downstream migrations of Black Lake juvenile sockeye salmon and the early stock's lack of an age 1 component.

As previously stated, age 1 sockeye salmon had significantly lower energy densities than their younger counterparts. These differences may result from the added energy costs associated with smoltification of age 1 fish (Groves 1970), migratory movement up and downstream in the watershed, or may be the remainder of energy densities following overwintering (Berg and Bremset 1998). For fish that rear in Chignik Lagoon, osmoregulation costs may also be incurred from tidal influences.

However, because it is currently not possible to identify Black Lake fish after they migrate downstream, it cannot be accurately determined if they can gain enough mass and/or energy reserves to smolt that year or if they will overwinter in Chignik Lake, let alone how their presence will impact the late stock. Figure A-1, based on all ADF&G ecological assessment beach seine captured sockeye salmon in the Chignik watershed in 2002 illustrates the considerable overlap in length frequency (mm) among age classes and size groups. No significant differences in energy density were observed among Chignik Lake, Chignik River, and Chignik Lagoon sockeye salmon with respect to size class or age. This is important to consider because it indicates that age 0 fish can reach lengths comparable to outmigrating age 1 fish, and may be capable of smolting and leaving the watershed as age 0 fish. Rice et al. (1994) have observed that age 0 sockeye salmon

migrated to the ocean, and survived, when freshwater rearing conditions were resource limited. This same rearing strategy may apply to Black Lake fish if they cannot achieve energy density levels to meet the costs of overwintering in Chignik Lake, where intraspecific competition and piscivorous predation are present (Metcalfe and Thorpe 1992; Ruggerone et al. 1999). As evidenced by adult sockeye salmon returning to the Chignik watershed with age 0 freshwater scale patterns, top-down grazing pressure and competition for zooplankton forage may cause decreased or limited growth in those overwintering fish and induce a seaward migration in fish energetically unprepared for smoltification or overwintering (Rice et al. 1994; Bouwens and Finkle 2003).

Mean energy densities, lengths, and dry weights also fluctuated over time in each location for age 1 sockeye salmon. Declines in mean length over time, may indicate migration as it is unlikely that Chignik juvenile sockeye salmon shrink. That these negative trends occurred either mid to late season in Chignik Lake, Chignik River, and Chignik Lagoon might be explained by two possible strategies; (1) the larger individuals smolt before the smaller ones and leave the watershed (Morgan et al. 2002) and (2) the addition of smaller Black Lake fish to the lower parts of the watershed offset increases relative to length. By July, the mean lengths of age 0 sockeye salmon in Black Lake, Chignik Lake, Chignik River, and Chignik Lagoon were 46.3 mm, 54.7 mm, 51.9 mm, and 51.0 mm respectively (Bouwens and Finkle 2003). While it is difficult to consider what kind of growth Black Lake fish could gain in the lower parts of the watershed, the potential for such a case does exist and should be considered when making comparisons among all four rearing locations in the watershed.

From the temperature similarities between Black Lake and Chignik Lagoon, one

might infer that fish rearing in the lagoon would also have high growth rates. By comparing mean energy densities, length, and dry weight over time by age class, age 0 fish did increase in length and dry weight throughout the study period but had continued declines in energy density. Age 1 sockeye salmon experienced increases in mean energy density, length, and dry weight but only until the middle of July. Consequently, this suggests that other factors were more influential than temperature on fish rearing in the lagoon. As stated earlier, osmoregulation and smoltification are energetically costly (Groves 1970; Moyle and Cech 1982).

Competition in Chignik Lagoon may also be a significant source of energy expenditure for juvenile sockeye salmon. Digestive tract data revealed that crustaceans were the most consumed ration and were an abundant food source in Chignik Lagoon (Bouwens and Finkle 2003). However, crustaceans, such as amphipods or pericardians, may not be the most energetically beneficial food source for lagoon rearing fish as they are not as digestible as zooplankton or larval insects (Davis et al. 1998), but would still consume energy via assimilation and evacuation. Digestive tract fullness (Table A-8) was also significantly lower in Chignik Lagoon compared to Black Lake, which would indicate competition or lack of forage as another limiting factor.

Variations in energy density in the Chignik watershed have been shown to represent many different scenarios that a juvenile fish may encounter in a rearing environment. The addition of energy density data has also proven valuable in that it has elucidated some of the reasons behind the life history strategies of Chignik watershed juvenile sockeye salmon that length and weight data alone could not accurately define. The incorporation of energy density data has shown that length-weight relationships are

highly variable for juvenile fish and that energy density data can effectively capture the variation in condition that occurs over the stanzas of juvenile fish growth. Energy density data have also illustrated the influence of temperature on Black Lake fish life history strategies.

Current management practices weight escapement goal targets of the watershed based on spawner-recruit, zooplankton, and smolt outmigration data (Bouwens and Finkle 2003). The incorporation of bioenergetic data may also prove to be useful management tool. In light of the morphological changes to the Chignik watershed, bioenergetic data could locate and identify the connections among trophic levels in each nursery lake, which impact carrying capacity, and thus escapement (Beauchamp et al. 1989). Comparisons of abundance for all species, their diet composition relative to available forage, and juvenile sockeye salmon energy densities for each nursery lake could indicate resource limitations (Negus 1995). Bioenergetic data alone could also be used to establish condition thresholds to improve survival estimates. Specifically, proximate analyses, based on lipid and protein content, would be useful in determining rearing conditions conducive to growth. Stock identification would naturally enhance an understanding of Chignik juvenile sockeye salmon rearing strategies, and paired with bioenergetic data, could clarify the ambiguous relationships of Chignik Lake fish.

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Appendices

Table A-1. Average number of zooplankton per m^2 from Black Lake, by sample date, 2002. "Ovig." refers to ovigerous plankton. From Bouwens and Finkle 2003.

Taxon	Sample Date 5/25	6/22	7/19	8/15	9/1	Seasonal Average
Copepods:						
Epischura	0	663	2,123	12,633	7,166	4,517
Ovig. *Epischura*	0	0	0	0	0	0
Diaptomus	13,535	663	0	1,115	1,592	3,381
Ovig. *Diaptomus*	0	0	0	0	0	0
Cyclops	27,070	13,270	26,539	57,962	73,248	39,618
Ovig. *Cyclops*	0	0	0	0	0	0
Harpaticus	0	0	0	0	0	0
Napulii	18,047	8,625	10,616	21,178	16,720	15,037
Total copepods	58,652	23,222	39,278	92,888	98,726	62,553
Cladocerans:						
Bosmina	0	12,606	64,756	135,244	286,624	99,846
Ovig. *Bosmina*	0	0	25,478	62,420	46,975	26,975
Daphnia l.	0	0	0	0	0	0
Ovig. *Daphnia l.*	0	0	0	0	0	0
Chydorinae	0	0	11,677	62,049	18,312	18,408
Total cladocerans	0	12,606	101,911	259,713	351,911	145,228
Total copepods + cladocerans	117,304	59,050	180,467	445,489	549,363	270,335

Table A-2. Average number of zooplankton per m^2 from Chignik Lake, by sample date, 2002. From Bouwens and Finkle 2003

Taxon	Sample Date					Seasonal Average
	5/7	5/22	6/19	7/24	8/14	
Copepods:						
Epischura	0	299	3,981	26,805	68,206	19,858
Ovigerous *Epischura*	0	0	0	0	0	0
Diaptomus	0	166	7,066	29,857	33,705	14,159
Ovigerous *Diaptomus*	0	0	0	1,858	7,697	1,911
Cyclops	42,795	78,888	90,549	93,020	66,348	74,320
Ovigerous *Cyclops*	0	166	1,095	11,611	16,189	5,812
Harpaticus	0	0	299	1,679	1,062	608
Nauplii	20,734	14,464	21,066	42,994	106,423	41,136
Total copepods:	63,528	93,982	124,055	207,823	299,629	157,803
Cladocerans:						
Bosmina	0	0	4,744	41,534	93,952	28,046
Ovigerous *Bosmina*	0	0	498	15,658	23,089	7,849
Daphnia longiremis	829	133	1,061	12,075	28,132	8,446
Ovigerous *Daphnia longiremis*	0	298	199	4,247	16,189	4,187
Chydorinae	0	0	2988	8691.5	8758	4,088
Total cladocerans:	829	431	9,490	82,205	170,119	52,615
Total Copepods + Cladocerans	64,358	94,413	133,544	290,028	469,748	210,418

Table A-3. Biomass estimates (mg dry weight/m^2) of the major Black Lake zooplankton taxa by sample date, 2002.

From Bouwens and Finkle 2003

	2002						
	Sample Date					Seasonal	Weighted
Taxon	5/25	6/22	7/19	8/15	9/1	Average	Average
Copepods:							
Epischura	0.00	0.81	2.59	15.41	8.74	4.70	2.48
Diaptomus	38.45	1.89	0.00	3.17	4.52	10.88	7.36
Cyclops	16.19	7.93	15.87	34.66	43.80	18.66	26.94
Harpaticus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total copepods	54.64	10.63	18.46	53.24	57.07	34.24	36.78
Cladocerans:							
Bosmina	0.00	9.94	51.05	106.63	225.98	41.91	80.89
Ovigerous *Bosmina*	0.00	0.00	32.34	79.23	59.62	27.89	34.79
Daphnia longiremis	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chydorinae	0.00	0.00	1.29	6.88	2.03	2.04	9.96
Total cladocerans	0.00	9.94	84.69	192.73	287.63	71.84	125.64
Total Biomass	54.64	20.57	103.15	245.97	344.70	106.08	162.42

Table A-4. Biomass estimates (mg dry weight/m^2) of the major Chignik Lake zooplankton taxa by sample date, 2002. From Bouwens and Finkle 2003.

Taxon	Sample Date					Seasonal Average	Weighted Average
	5/7[a]	5/22	6/19	7/24	8/14		
Copepods							
Epischura	0.00	0.54	6.46	35.46	82.56	25.00	16.71
Ovigerous *Epischura*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diaptomus	0.00	0.93	26.51	127.44	143.02	59.58	58.24
Ovigerous *Diaptomus*	0.00	0.00	0.00	11.87	47.89	11.95	13.66
Cyclops	42.45	87.03	107.64	109.49	76.86	84.69	102.45
Ovigerous *Cyclops*	0.00	0.54	3.76	42.93	59.40	21.33	30.10
Harpaticus	0.00	0.00	0.20	0.18	0.18	0.11	0.46
Total Copepods:	42.45	89.03	144.58	327.38	409.91	202.67	221.62
Cladocerans							
Bosmina	0.00	0.00	4.25	35.95	80.73	24.19	28.30
Ovigerous *Bosmina*	0.00	0.00	0.70	22.29	32.95	11.19	12.54
Daphnia longiremis	0.87	0.17	1.17	14.18	35.13	10.30	17.05
Ovigerous *Daphnia longiremis*	0.00	1.06	0.61	13.78	55.27	14.14	16.99
Chydorinae	0.00	0.00	0.37	1.11	1.17	0.53	3.47
Total Cladocerans:	0.87	1.23	7.10	87.30	205.25	60.35	78.36
Total Biomass	43.32	90.26	151.68	414.68	615.16	263.02	299.98

Table A-5. Average length (mm) of macrozooplankton in Black Lake by sample date, 2002. From Bouwens and Finkle, 2003.

	2002					
	Sample Date					Seasonal
Taxon	5/25	6/22	7/19	8/15	9/1	Average
Copepods:						
Epischura		1.18	0.42	0.45	0.48	0.79
Diaptomus		1.24		0.68	0.67	0.63
Cyclops	0.59	0.42	0.42	0.45	0.44	0.47
Harpaticus						0.20
Nauplii	0.15	0.24				0.20
Cladocerans:						
Bosmina		0.30	0.29	0.29	0.31	0.32
Ovigerous *Bosmina*			0.36	0.38	0.38	0.37
Daphnia l.						n/a
Chydorinae			0.23	0.25	0.26	0.24
Other:						
Ostracoda						n/a

Table A-6. Average length (mm) of macrozooplankton from Chignik Lake, by sample date, 2002. From Bouwens and Finkle, 2003.

	2002					
	Sample Date					Seasonal
Taxon	5/7[a]	5/22	6/19	7/24	8/14	Average
Copepods:						
Epischura		0.86	0.83	0.54	0.50	0.68
Ovigerous *Epischura*						n/a
Diaptomus		1.11	1.12	0.90	0.95	1.02
Ovigerous *Diaptomus*				1.21	1.1125	1.16
Cyclops	0.39	0.55	0.67	0.53	0.61	0.55
Ovigerous *Cyclops*		0.80	0.96	0.99	1.11	0.96
Harpaticus			0.44	0.46	0.48	0.46
Nauplii	0.27	0.26	0.26			0.26
Cladocerans:						
Bosmina			0.33	0.29	0.31	0.31
Ovigerous *Bosmina*			0.43	0.39	0.39	0.40
Daphnia longiremis	0.48	0.63	0.60	0.49	0.54	0.55
Ovigerous *Daphnia longiremis*		0.94	0.82	0.90	0.83	0.87
Chydorinae			0.29	0.26	0.28	0.28

[a]Only station two sampled.

Table A-7. Beach seine catch data, 2002.From Bouwens and Finkle 2003.

Location	Site	Date	Water temp (°C)	Sockeye salmon > 45 mm	Sockeye salmon < 45 mm	Sockeye salmon Total	Coho	King	Stickleback	Pond smelt	Dolly Varden	Other
Chignik Lake	1	5/18	6.5	0	0	0	2	0	0	0	1	0
	1	6/4	7.0	0	0	0	0	0	0	0	0	0
	1	6/18	8.0	2	3	5	1	0	0	0	2	0
	1	7/3	11.5	9	0	9	4	1	0	0	21	0
	1	7/18	11.5	23	0	23	23	2	0	1	7	0
	1	8/5	11.0	2	0	2	8	0	5	0	16	0
Chignik Lake	2	6/4	7.5	67	0	67	3	3	0	0	3	0
	2	6/18	9.0	4	0	4	1	0	0	0	1	0
	2	7/3	11.0	3	16	19	0	0	1	0	0	1 sculpin
	2	7/18	11.0	9	0	9	14	1	0	9	27	1 steelhead, 1 chum
	2	8/5	12.0	31	0	31	2	0	5	46	57	0
Chignik Lake	3	5/18	5.0	0	1	1	0	0	1	0	0	0
	3	6/4	7.0	3	0	3	1	1	0	0	116	0
	3	6/18	9.0	1	6	7	1	0	0	0	5	0
	3	7/3	8.0	0	0	0	0	0	0	0	3	1 sculpin
	3	7/18	9.0	0	0	0	0	0	0	0	0	0
	3	8/5	11.5	0	0	0	22	0	7	7	26	0
Chignik Lake	5	5/18	7.0	65	0	65	8	19	23	0	25	3 sculpin
	5	6/4	8.0	123	1	124	12	6	162	0	10	0
	5	6/18	11.0	4	5	9	0	0	10	0	0	1 sculpin
	5	7/3	10.0	82	38	120	14	0	14	1	26	3 sculpin
	5	7/18	10.5	167	0	167	41	1	72	35	82	12 steelhead
	5	8/5	10.0	6	0	6	0	0	1	1	0	0
Chignik Lake	6	5/20	7.0	65	0	65	3	2	3	0	1	0
	6	6/4	9.0	19	0	19	1	0	0	0	0	0
	6	6/18	12.0	8	0	8	3	3	4	0	3	0
	6	7/3	10.5	3	13	16	0	0	1	0	1	2 sculpin
	6	7/18	10.0	6	0	6	2	0	0	0	0	0
	6	8/5	12.5	0	0	0	1	0	0	0	0	0

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Table A-7. Beach seine catch data, 2002. From Bouwens and Finkle 2003. (page 2 of 4)

Location	Site	Date	Water temp (°C)	Sockeye salmon > 45 mm	Sockeye salmon < 45 mm	Sockeye salmon Total	Coho	King	Stickleback	Pond smelt	Dolly Varden	Other
Chignik Lake	7	5/20	7.0	19	0	19	0	0	28	0	1	0
	7	6/4	13.5	33	0	33	11	9	4	0	3	0
	7	6/18	10.0	9	1	10	3	1	1	0	0	1 sculpin
	7	7/3	11.0	15	2	17	2	0	43	0	3	1 steelhead
	7	7/18	11.5	15	0	15	7	1	22	0	17	0
	7	8/5	12.5	11	0	11	2	0	13	0	1	1 sculpin
Chignik Lake	8	5/20	7.0	1	0	1	6	2	0	0	0	0
	8	6/4	8.5	23	0	23	20	11	68	0	13	2 sculpin
	8	6/18	9.5	73	0	73	54	28	291	1	23	0
	8	7/3	11.5	31	0	31	13	11	25	0	0	1 steelhead
	8	7/18	12.5	15	0	15	17	1	95	0	12	2 steelhead
	8	8/5	12.0	84	0	84	33	1	163	6	27	2 steelhead
Chignik River	1	5/17	5.7	700	300	1000	50	0	1000	1	2	3 sculpin
	1	6/1	8.0	114	0	114	13	5	49	2	0	2 sculpin
	1	6/14	9.0	807	1	808	2	0	29	0	0	0
	1	6/28	10.0	1600	400	2000	7	9	100	200	8	0
	1	7/13	10.5	229	19	248	11	1	4	2	4	4 sculpin
	1	7/29	11.0	321	1	322	18	0	29	22	3	3 sculpin
Chignik River	2	5/17	6.5	94	25	119	13	6	162	1	1	4 flounder, 1 sculpin
	2	6/1	7.5	124	24	148	14	17	409	2	2	4 flounder, 1 sculpin
	2	6/14	9.0	128	8	136	5	3	131	3	6	1 flounder, 4 sculpin
	2	6/28	10.0	860	40	900	24	10	195	70	3	1 sculpin, 1 flounder
	2	7/13	11.5	217	53	270	25	0	155	5	2	1 chum
	2	7/29	12.0	269	8	277	26	0	475	0	0	2 sculpin, 3 flounder
Chignik River	3	5/17	5.0	99	0	99	26	20	5	3	5	1 flounder
	3	6/1	9.0	113	13	126	44	11	305	0	7	2 flounder
	3	6/14	9.0	46	5	51	24	24	62	3	11	1 sculpin
	3	6/28	10.0	143	1	144	28	8	0	4	4	1 sculpin

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Table A-7. Beach seine catch data, 2002. From Bouwens and Finkle 2003. (page 3 of 4)

Location	Site	Date	Water temp (°C)	Sockeye salmon > 45 mm	Sockeye salmon < 45 mm	Sockeye salmon Total	Coho	King	Stickleback	Pond smelt	Dolly Varden	Other
	3	7/13	11.0	44	13	57	3	24	426	0	7	4 chum
	3	7/29	11.0	385	14	399	32	4	26	26	0	1 flounder
Lagoon	1	5/16	5.0	2	0	2	0	0	0	0	1	0
	1	6/1	7.0	120	13	133	2	0	1	1	0	0
	1	6/15	14.0	61	6	67	0	5	4	0	0	0
	1	6/29	16.0	565	55	620	18	41	194	3	9	0
	1	7/15	10.5	553	2	555	20	25	1	5	7	2 steelhead
	1	7/30	11.0	140	4	144	0	1	11	0	3	0
Lagoon	2	5/7	6.5	1	8	9	0	0	0	0	0	1 flounder
	2	6/1	9.5	4	40	44	0	0	4	0	0	3 flounder, 4 sculpin
	2	6/15	13.0	192	6	198	1	0	0	0	0	0
	2	6/29	14.5	88	0	88	3	4	17	0	9	0
	2	7/15	12.0	12	1	13	0	0	0	0	2	0
	2	7/30	13.0	6	1	7	0	0	2	0	0	0
Lagoon	3	5/17	6.0	0	0	0	0	0	0	0	13	0
	3	6/1	8.0	3	0	3	0	0	0	0	0	32 humpies
	3	6/15	13.0	478	0	478	2	1	0	0	145	4 humpies
	3	6/29	13.0	17	0	17	0	0	1	0	8	0
	3	7/16	12.5	8	0	8	0	0	0	0	6	5 sculpin
Lagoon	4	5/7	5.0	2	0	2	0	0	0	0	0	0
	4	5/16	8.0	1	3	4	0	0	0	0	1	0
	4	6/1	9.0	24	58	82	0	0	20	2	0	26 flounder
	4	6/15	13.0	7	616	623	0	0	1	3	0	7 flounder, 5 isopods
	4	6/29	15.0	43	2	45	0	1	1	0	0	7 flounder, 8 isopods
	4	7/15	12.0	200	34	234	0	3	2	3	5	1 sculpin, 1 flounder
	4	7/30	13.0	17	7	24	0	0	1	1	0	23 sculpin, 1 flounder

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Table A-7. Beach seine catch data, 2002. From Bouwens and Finkle 2003. (page 4 of 4)

Location	Site	Date	Water temp (°C)	Sockeye salmon >45 mm	Sockeye salmon <45 mm	Sockeye salmon Total	Coho	King	Stickleback	Pond smelt	Dolly Varden	Other
Lagoon	5	5/7	6.0	38	0	38	0	0	0	0	38	0
Black Lake	1	5/28	9.0	0	551	551	4	0	9	0	0	0
	1	6/7	11.5	0	978	978	0	0	31	0	0	0
	1	6/22	14.0	66	578	644	2	0	128	1	0	1 sculpin
	1	7/6	14.0	170	394	564	2	0	6	3	0	1 sculpin
	1	7/20	14.5	75	68	143	9	0	0	198	0	0
	1	8/7	16.0	5	0	5	16	0	16	0	0	0
Black Lake	2	5/28	10.5	0	4	4	0	0	0	0	0	0
	2	6/22	16.0	138	138	276	0	0	1	2	0	0
	2	7/6	14.0	0	2	2	0	0	0	5	0	0
	2	8/7	15.5	0	0	0	0	0	0	8	0	2 sculpin
Black Lake	4	5/28	10.5	0	311	311	0	0	1	0	0	0
	4	6/7	9.5	0	28	28	0	0	0	0	0	0
	4	6/22	15.0	0	79	79	0	0	7	0	0	0
	4	7/6	14	0	39	39	0	0	0	4	0	0
	4	8/7	15.5	1	0	1	1	0	10	8	0	0
Black Lake	5	5/28	8.5	0	99	99	1	0	6	0	0	0
	5	6/7	11.5	8	74	82	47	3	178	0	0	0
	5	6/22	15.5	375	375	750	100	0	200	0	0	0
	5	7/6	14.5	328	257	585	2	0	76	0	0	1 sculpin
	5	7/20	13.5	15	4	19	15	0	54	0	0	0
	5	8/7	16.0	6	0	6	16	0	700	0	0	0

Table A-8. Digestive tract (DT) fullness of Chignik watershed juvenile sockeye salmon, 2002. DT fullness is a percentage of total body weight.

Location	Date	DT	N	SE
Black Lake	28-May-02	21.25%	16	1.42%
	7-Jun-02	17.34%	15	1.61%
	22-Jun-02	21.10%	20	1.26%
	6-Jul-02	16.30%	15	1.23%
	13-Jul-02	13.49%	10	0.93%
	20-Jul-02	14.88%	15	0.88%
	7-Aug-02	23.83%	6	13.28%
Chignik Lake	20-May-02	13.05%	5	1.15%
	30-May-02	8.40%	10	0.51%
	4-Jun-02	11.46%	27	0.76%
	3-Jul-02	14.35%	26	1.14%
	18-Jul-02	11.50%	25	0.96%
	26-Jul-02	12.50%	1	NA
	5-Aug-02	10.38%	17	0.52%
	13-Aug-02	7.14%	1	NA
Chignik River	17-May-02	12.28%	8	1.14%
	18-May-02	14.32%	10	1.53%
	24-May-02	12.50%	1	NA
	14-Jun-02	13.78%	15	2.22%
	28-Jun-02	15.72%	15	1.24%
	13-Jul-02	13.26%	5	0.75%
	16-Jul-02	3.23%	1	NA
	29-Jul-02	11.84%	15	0.86%
	9-Aug-02	10.47%	5	1.93%
Chignik Lagoon	7-May-02	14.01%	7	2.15%
	15-Jun-02	14.56%	20	1.19%
	29-Jun-02	14.16%	20	1.59%
	15-Jul-02	13.60%	11	1.85%
	16-Jul-02	33.95%	3	21.51%
	30-Jul-02	12.65%	12	1.01%

Table A-9. Average fish weight, stomach weight, and total number of identifiable prey items, by group, of juvenile sockeye salmon from throughout the Chignik watershed, 2002. From Bouwens and Finkle 2003.

Location	n		Fish WT (g)	Stomach WT (g)	Cladocerans	Copepods	Chironomids	Other Insect	Crustacea[a]
Black Lake	97	Average	0.7	0.1	4.3	17.4	16.3	1.8	0.0
		Standard Dev.	0.4	0.1	11.7	22.4	13.3	2.6	0.0
Black River	12	Average	0.6	0.1	2.5	0.7	8.6	0.0	0.0
		Standard Dev.	0.1	0.0	1.5	0.4	2.2	0.0	0.0
Chignik Lake	126	Average	2.6	0.3	1.7	57.6	18.2	0.5	0.0
		Standard Dev.	1.6	0.2	6.0	123.1	24.2	0.8	0.1
Chignik River	90	Average	2.0	0.3	1.9	24.4	10.8	0.3	0.2
		Standard Dev.	1.2	0.2	6.6	40.0	8.8	0.3	0.5
Chignik Lagoon	88	Average	2.4	0.3	4.5	106.3	5.2	0.0	13.5
		Standard Dev.	1.4	0.2	14.3	144.3	6.2	0.1	14.5
Entire System	413	Average	1.9	0.2	3.0	49.9	13.1	0.2	2.9
		Standard Dev.	1.9	0.3	20.4	191.4	27.6	3.4	14.5

[a] Crustacea consisted primarily of pericaridans (609 counted individuals) and amphipods (302 counted individuals).

Figure A-1. Length frequency histogram by size group and age for Chignik watershed sockeye salmon, 2002. These data are from all fish captured the ADF&G ecological assessment. Sample size = 1405 fish.